Cut Mark Analysis of Protohistoric Bison Remains from EfPm-27 Utilizing the Scanning Electron Microscope

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Abstract

EfPm-27 is a Protohistoric bison pound and processing site located in Fish Creek Park in Calgary, Alberta. The site exhibited the presence of metal tools and macroscopically deceptive cut marks suggesting the potential for the presence of both metal and stone cut marks. Moulds of selected cut marks from the assemblage were made and examined with the scanning electron microscope (SEM) to verify or negate the use of metal tools for butchery at the site. SEM images of the cut mark moulds reveal micromorphology that is similar to experimental and published stone tool cut mark SEM images. No evidence for the use of metal tools for butchering was identified.

Protohistoric sites research could benefit from the use of SEM analysis of cut marks to distinguish between stone and metal tool use. This would provide important secondary evidence for metal trade items in scenarios where such artifacts may be beyond recovery. Conversely, the presence of metal artifacts at a site does not necessarily imply that they were used for butchery and this assertion must be verified by the presence of metal cut marks.

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Abbreviations

AFTE	Association of Firearm and Tool Mark Examiners
SEM	Scanning Electron Microscope/Microscopy
UTM	Universal Transverse Mercator

Chapter 1

Introduction

1.1. Introduction to Thesis Topic

When an animal is butchered, the tools used sometimes contact the bone. This activity can leave behind tool marks on the bone that allow archaeologists to identify what sort of tool was used and how. Often the type of tool used, such as a saw, an axe, or a knife, can be identified just by examining the mark with the naked eye. However, microscopic features of cut marks that can help differentiate between tool material types must be examined using a Scanning Electron Microscope (SEM).

The site used for this project, EfPm-27, is a Protohistoric *Bison bison* pound and processing site located in Fish Creek Park in Calgary, Alberta (Wickham 2005). Being a Protohistoric site, EfPm-27 provided the potential for the presence and utilization of both metal and stone tools. Using the SEM it is possible to differentiate between metal and stone cut marks and thereby identify whether both sorts of tools were being utilized for butchering or whether stone tools were being utilized exclusively.

Research on Protohistoric sites on the Plains benefits from the application of SEM analysis of cut marks to distinguish between stone and metal tool use. This information provides important secondary evidence for metal trade items in a scenario where such artifacts may be beyond recovery. Several researchers (e.g. Walker and Long 1977:606; Potts and Shipman 1981:579) have noted that cut marks studies can be employed to identify tool use at an archaeological site even if no associated tools were found.

SEM studies of cut marks have been used to investigate the origins of metallurgy in the Old World, early tool use in Africa, and instances of warfare and cannibalism, as well as in forensic studies. Until now, it has never been employed to study Protohistoric faunal materials on the Plains for this purpose. This is not necessarily a problem in terms of clearly pre-contact or clearly European origin sites with multiple lines of evidence that can reliably reinforce the assumption of tool material type. However, in Protohistoric sites, transitional sites, or multi-cultural sites this may be considered a deficit in data.

This project was designed to examine the cut marks at EfPm-27 primarily to validate or negate the presence of metal tool-made cut marks on *B.bison* bones from the site. The faunal materials from EfPm-27 provided an excellent opportunity to apply the SEM to cut mark analysis of a Protohistoric Plains assemblage for several reasons: 1) the EfPm-27 faunal material has already been processed in its majority and the upper levels include a recognized Protohistoric component; 2) the potential for metal cut marks had previously been identified macroscopically; 3) there is potential for future further comparison with prehistoric material both from deeper levels of the same site and similar sites within the park; 4) time, budgetary, and assemblage availability concerns; and 5) the importance of utilizing previously excavated assemblages to their utmost potential.

Considering both the overall absence of metal knives at the site and the arguments of several researchers that metal cut marks cannot be identified without the use of the SEM, it was assumed that the presence of metal cut marks had yet to be identified. Following basic Popperian principles (Domínguez-Rodrigo 2008) a simple null hypothesis, that metal cut marks are not present at EfPm-27, was constructed. In light of the evidence of the presence of stone tools at the site and initial macroscopic observations, the absence of stone cut marks was deemed to be unlikely and was not included as part of the hypothesis.

The goals of the current research included: 1) investigate the usefulness of SEM as a tool in Protohistoric studies; 2) identify metal tool derived cut mark absence or presence and extent at EfPm-27; 3) inter-site comparison of Protohistoric cut marks taking into account variation between metal and stone tool cut mark distribution; and 4) enrich the understanding of Protohistoric butchering practices and tool usage. In practice, goals number 1 and 2 became the crux of the study.

1.2. Chapter Overview

In Chapter 2, I will briefly introduce the site, EfPm-27 by first identifying its location and environmental context; secondly, by briefly reviewing past archaeological investigations at the location; and thirdly, by describing the evidence identifying the Protohistoric component of the assemblage, including relevant artifacts, radiocarbon dates, and past identifications.

In the first section of Chapter 3, I will introduce taphonomic analysis, relevant terminology, and the theoretical approaches with the most bearing on this thesis. The second section gives a literature review of four general groupings of tool mark and pseudo-tool mark investigation. However, there is often overlap in the subject matter and methodology of relevant archaeological and taphonomic investigations that make no use of the SEM, forensic studies, experimental and ethnographic studies, and tool mark studies which employ the SEM. This overlap is addressed within each section.

Chapter 3.2.1 highlights investigations of tool marks in zooarchaeological, ethnoarchaeological, and experimental studies. Relevant zooarchaeological data can include everything from the zooarchaeological components of a site report to broad-scale faunal investigations. Most such studies will necessarily employ data derived from ethnographic and/or experimental means and will often incorporate small-scale experimentation into the work being done; for example, to produce a comparative sample collection. Ethnographical, ethnoarchaeological studies of butchering processes and experimental examinations of taphonomic processes have provided the groundwork for the understanding of how, why, and where tool marks are produced. Relevant studies are geographically and topically diverse but provide much of the knowledge regarding taphonomic processes and damage morphology.

The next section describes various investigations of taphonomically significant cases of natural modification of bone surfaces. These are primarily experimental and observational studies providing important comparative and contextual information.

Chapter 3.2.3 describes forensic, physical anthropological, and palaeoanthropological studies dealing with tool marks. These include modern and ancient case studies as well as experimental investigations, often drawing from a different knowledge base than archaeology.

The final section of Chapter 3 includes aspects of the previous sections as it reviews specific examples and concerns of zooarchaeological, forensic, experimental, ethnographic, and palaeontological applications of the SEM. A suite of information concerning applications of the SEM in zooarchaeology and specifically towards the analysis of tool marks and pseudo-tool marks has been produced that spans several disciplines, from molecular medicine and dentistry to archaeology and palaeontology. Such studies that employ the SEM to study damage on bone surfaces have methodological and conceptual elements in common and are of particular relevance to this thesis.

Chapter 4 examines how an effective and thorough investigation of marks on bone might be undertaken. The various morphological criteria and distinguishing features that have been used by archaeologists to characterize and identify several forms of tool marks and pseudo-tool marks are described using specific illustrative examples from EfPm-27 and FbNo-24. Colour versions of these and all other images contained in this thesis are available in digital format (on the accompanying CD if available, in the online pdf version of this thesis, or from the author).

Chapter 5 reviews the methodology and procedures used during the acquisition of data for this study. This was completed in four phases, including a macroscopic analysis of the selected assemblage, the production of comparative experimental cut marks, the examination of comparative historic cut marks, functional and SEM comparison of available replicative mould-making materials, and the examination of selected samples using the SEM.

Chapter 6 describes the results of each of the four methodological phases of data acquisition. Each section includes a sub-section identifying and explaining potential sources of error that were identified before, during, and after each step. Results and sources of error are illustrated using representative examples and images from each phase.

Chapter 7 discusses the results and their potential meaning in four sections. In the first section, an overview of the SEM study is given including its indications regarding the assemblage and a direct comparison of the experimental, historic, and EfPm-27 cut marks. In the next section, interpretations of the observations made of the experimental stone tools are given within the context of how this might have affected the cut marks. In the third section, the generalized cut mark distribution pattern and how it relates to the possible butchering processes at the site is examined. Finally, a discussion of how the data from EfPm-27 compare to the selected sites, EgPn-430 (Vivian et al 2005a, 2005b) and DjPm-115 (Lensen 1995), and recommendations for possible future research at these sites is given.

In Chapter 8, I provide a summary of my conclusions and recommendations for further study. These will include a discussion of cut marks in Protohistoric faunal assemblages as well as the usefulness and applicability of the SEM as a tool for studying these types of sites.

The attached appendices are meant to illustrate and provide supplemental information and documentation without interrupting the flow of text. Appendix A provides a list of the identified cut marks from the assemblage and their locations as well as line diagrams of elements with cut marks in the assemblage. Appendix B gives images of the experimental cut mark production process, pre-defleshing close-ups, and representative SEM images of each of the marks used. Appendix C compares and contrasts the different mould materials employed in the analysis.

Chapter 2

EfPm-27: Site Setting and Previous Research

2.1. Site Location

EfPm-27 is located in Fish Creek Provincial Park, in Calgary, Alberta, West of the South end of Bow Bottom Trail Southeast (Figures 1, 2, and 3). Fish Creek Provincial Park is the largest Canadian provincial park located within city limits. It has a long and rich human history with over 80 identified archaeological sites. These sites are comprised of both pre-contact and historic archaeological resources, including the Calgary area's first Euro-Canadian settlement, EfPm-161 (the Bow Valley Ranch site), first dating to 1873 (Walde et al. 2001:40; Government of Alberta 2008).

The site of EfPm-27 is a *B.bison* kill site located on the slope above the terrace near the creek valley, west of the interpretive centre. This is south of the main walkway and west of a small adjoining pathway (Figure 3). Its UTM coordinate location is 11UQG086436 and its Legal Land Description is SE¼ of Section 35, Township 22, Range 1, west of the 5th Meridian.

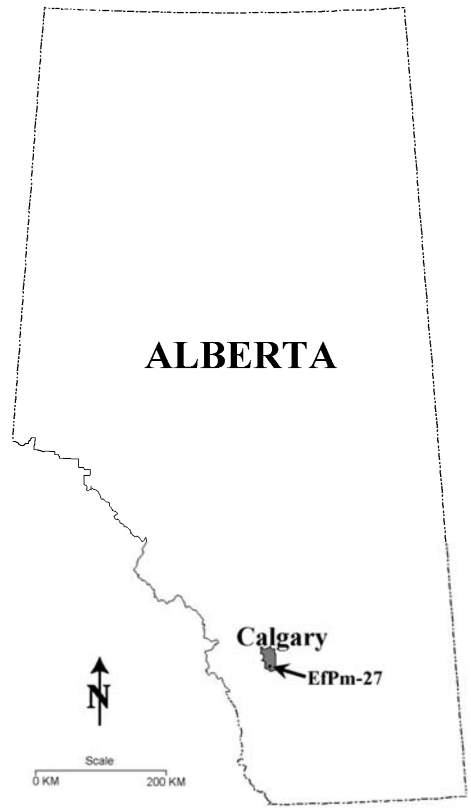

Figure 1. Map of location of EfPm-27 in Fish Creek Provincial Park, Calgary, Alberta.

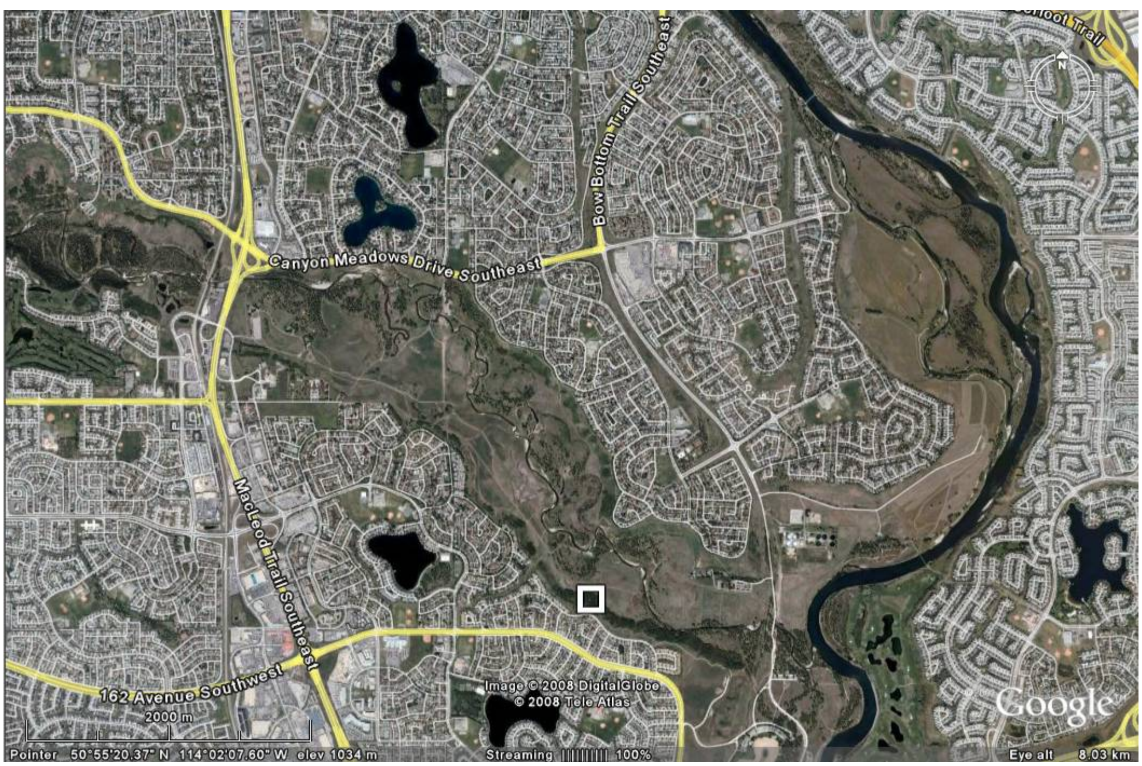

Figure 2. Satellite image of location of EfPm-27 in Fish Creek Park, Calgary, Alberta. Square indicates site location. Image from Google Earth™ mapping service, 2008.

Figure 3. Close-up satellite image of location of EfPm-27 in Fish Creek Park, Calgary, AB. Square indicates site location. Image from Google Earth™ mapping service, 2008.

2.2. Previous Investigations

EfPm-27 was discovered in 1968 by B.O.K. Reeves in association with the University of Calgary Archaeological Survey (Reeves 1969). At the time, the site was surveyed and shovel tested with a recommendation for future excavation and mapping and it was noted that there were no other known previous collections at this location. However, Crowe-Swords and Hanna's (1980) report on the 1979 archaeological work suggests that previous excavations at EfPm-27 were conducted by field school students from the University of Calgary in 1968, although no detailed report on this work is available.

A report from the 1975 survey of Fish Creek Provincial Park conducted by Reeves and Anderson (1975) describe the site as a “bison pound where animals were driven over a gentle slope into a corral constructed below” (Reeves and Anderson 1975:10). They further suggest that “meatier cuts” would have been removed to camp sites nearby for further processing (Reeves and Anderson 1975:10). In the case of EfPm-27 this secondary processing site was probably EfPm-2.

The site was excavated in 1976 by Lifeways of Canada Limited, who suggested that the latest occupation was probably used by the Peigan as a primary carcass processing area for multiple winter kills (Smith et al. 1977). It was excavated again in 1979 by the University of Calgary (Crowe-Swords and Hanna 1980). The upper levels, relevant to this study, were designated as a Protohistoric *B.bison* kill site with a processing component, dating to AD1750±50 (Crowe-Swords and Hanna 1980:10).

The work at EfPm-27 from 1999 to 2002 ran under the Alberta Heritage Research Project at the University of Calgary and was excavated by students of the University of Calgary Fish Creek Archaeological Field School and participants in the Public Archaeology Program at Fish Creek. Michelle Wickham supervised the project as part of her Master of Arts degree requirements and Dr. Dale Walde acted as project director and field school instructor.

Wickham’s (2005) Masters Thesis should be consulted for a detailed layout of the excavated units and record of the faunal materials recovered from EfPm-27 by the University of Calgary. It provides a general faunal analysis of all of the material excavated by the University of Calgary Fish Creek Field School as well as reports on the project itself.

Wickham (2005) emphasized that the “most intense cultural activity is represented by the most recent cultural component, Old Women’s, which has been attributed to Protohistoric and Late Prehistoric cultural traditions” (Wickham 2005:9). Wickham’s (2005:15) work concluded that the site represents a *B.bison* kill with multiple kill events. Seasonality and sexing data for the Late Prehistoric and Protohistoric components of the site suggest it represents at least four superimposed kill events of two separate cow/calf herds and two separate bull herds, occurring from late Fall to early Spring (Wickham 2005:285-286).

2.3. Protohistoric Component

The Protohistoric is defined as a transitional period between Pre-Contact and Post-Contact, beginning with “the initial receipt of European goods by the aboriginal inhabitants of a region” and ending with “the arrival of Europeans in the area” (Ray 1978:26). In Western Canada, this is approximately between AD c1700 – c1790 (Pyszczyk 1997:50). As previously mentioned, the uppermost levels of EfPm-27, from zero to 45 cm below surface, have been designated as a Protohistoric *B.bison* kill site with a processing component, dating to AD1750±50 (Crowe-Swords and Hanna 1980:10). Both the artifact assemblage and radiocarbon dates support this assertion of a Protohistoric occupation.

It has been argued that Northern Plains native groups in the Protohistoric would have been out of the direct trade zone and subject to acquiring any metal trade goods indirectly second-hand (Pyszczyk 1997) or through middle-men traders (Ray 1978), and thus traditional material culture remained largely intact until more direct means of trade became available. This limited presence of trade goods amongst a predominantly Late Pre-contact/transitional assemblage is one of the key methods of identifying a Protohistoric site in the absence of other means (e.g. radiocarbon dates) (Ray 1978:26).

A limited number of trade goods (including beads and metal fragments), but no horse bones were discovered at EfPm-27, which is consistent with evidence used to date similar early Protohistoric sites (Vickers 1986:106). A metal projectile point was among the metal artifacts recovered during the 1976 excavations. It was described as:

> Metal point found in Area A level 1....Incomplete, consisting of a point tip of rusted, soft metal. Form is triangular with straight sides and pointed tip. 16.7mm wide at base, 1.3mm thick, weighing 1.2g. A European trade point or one cut from traded metal. [Smith et al. 1977:15]

This metal point was one in a collection of otherwise Plains Side Notched points dating to approximately 550 – 250BP (Vickers 1986:95). Metal projectile points were often produced from damaged kettles or other trade goods that had lost their original utility (Mirau et al. 1999:41). This would have been a common occurrence with these metal trade goods during the Protohistoric as they would have been traded and utilized multiple times before they finally reached the Northwestern Plains region. However, iron objects such as these are prone to a high rate of deterioration and, as a result, relatively few metal points are recovered from archaeological sites (Mirau et al. 1999:41).

The 1998 through 2000 Field School excavations recovered a fragment of iron and four glass beads in the uppermost component (Walde et al. 2001:34). Few trade items among an artifact assemblage that is predominantly aboriginal in origin corroborates a Protohistoric timeframe for this component. The 2001 excavations did not recover any trade artifacts that could further support a Protohistoric date for Component 1 (Wickham and Walde 2002). However, Wickham's (2005:34) work yielded one radiocarbon date on a metacarpal providing "a 95% probability of Cal AD 1650 to 1950".

Chapter 3

Literature Review

3.1. Introduction to Taphonomic Analysis and Theoretical Approach

Taphonomy was originally a palaeontological discipline focused on the study of the processes of burial and transition of organic materials from the biosphere to the lithosphere (Efremov 1940:84). Its use within zooarchaeology encompasses the study of all of the processes that occur after an animal's death. These include thanatic (factors contributing to the death of an animal) (Noe-Nygaard 1987:10), perthotaxic (postmortem impacts prior to burial), taphic (post-burial modification), and anataxic (re-exposure of buried bone) factors, both natural and cultural, contributing to deposition and presence in the archaeological record (Gilbert and Singer 1982:23-24). Shipman (1981a:12) explained two subdivisions of taphonomy include neotaphonomy and palaeotaphonomy, which are the study of contemporary taphonomic processes and the taphonomy of the fossil record respectively. Archaeotaphonomy falls between these two and is the study of the processes (both cultural and natural) that affect faunal remains in the archaeological record (Clark and Coinman 2003:234).

The basic data of archaeotaphonomic analyses are surface damages to the bones themselves. Damage morphology refers to patterns in the form, frequency, and anatomical distribution of this surface damage (O'Connell 1995:224). The study of damage morphology and changes to the bone surface is deemed the "physical approach" or the "physical attribute" taphonomic approach by Domínguez-Rodrigo et al. (2007:23). This is in contrast to what they called the "paleontological approach", which focuses on examination of features such as "differential representation of skeletal parts and the construction and interpretation of mortality profiles and taxonomic lists" (Domínguez-Rodrigo et al. 2007:23).

The causality of damage morphology occurs at several levels. Gifford-Gonzalez (1991:228-229) explained that an "actor" causes an "effector" to leave "trace" on a bone. The actor may be an animal chewing on or trampling a bone, a human butchering an animal, or a process such as erosion. The effector may be grains of sand, a tooth, or a stone or metal tool. The trace may take the form of various tool marks or pseudo-tool marks with specific damage morphologies. The "causal agent" (Gifford-Gonzalez 1991:228-229) or "causal component" (Fisher 1995:11) describes a more simplistic view of actor and effector, making no distinction as to differing specific sources. For example, a sharp stone being forced across the bone surface may describe a causal component with several potential specific actor/effector combinations. These terminological distinctions are important because they reflect different levels of interpretation of damage morphology.

Damage morphology analysis is a key aspect of the study of zooarchaeological remains. Many archaeological studies concern themselves with investigating damage morphology, its distinguishing features, and implications. This includes tool mark analysis, the focus of this thesis, which directly reflects human presence and activities. However, other reflections of taphonomic processes resulting in marks on bone have often been mistaken for tool marks and vice versa.

Pseudo-tool marks refer to marks on bone, caused by natural or traumatic taphonomic processes, that may mimic (or be mistaken for) true tool marks. Pseudo-tool marks can include pseudo-cut marks, which refer to bone surface damages that mimic true cut marks derived from slicing blades. An understanding of damage morphology and taphonomic processes that produce pseudo-tool marks is vital to the identification and analysis of tool marks.

The techniques of the analysis of pseudo-tool marks parallel those of tool marks and are often just as important to research objectives and coincide with them implicitly. Therefore, studies of natural taphonomic phenomena such as weathering and alterations resulting from carnivore, artiodactyl, rodent, or plant activity can serve to benefit the understanding of tool marks. This thesis, while focusing on fine cut marks, must also consider the many other forms of taphonomic damage that may mimic or mask cut marks. If the aforementioned interactions are kept in mind and identified during the analysis, one can distinguish as closely as possible a single aspect of the taphonomic evidence, the cut marks, and provide a building block for interpretation and comparison with other data.

It is important to consider the many potential lines of evidence that can be used to deduce the probable origin of a mark on a bone. Besides the microscopic and macroscopic features of the mark itself, these data can include everything from logistical information regarding position, orientation, or frequency of bone marks, to external variables such as presence/absence and associations of artifacts in the site, site context, depositional context, and ethnographic information. This holistic approach of considering and weighing multiple variables and lines of evidence in addition to the specific morphology of the mark is known as a "configurational approach" (Fisher 1995:16; Pickering and Wallis 1997:1124). Configurational analysis provides a much stronger argument than would be gleaned from relying on any single factor, especially considering the lack of morphological absolutes in damage morphology (Fisher 1995:16-17).

"Immanent properties" refer to constants within and between ecofacts, artifacts, or sites (Simpson 1963:24-25 in Lyman and O'Brian 1998:624). For example, these might include the physical properties of bone or the laws of deposition. In contrast, "configurational properties" are dynamic and idiosyncratic to the history of a particular ecofact; these properties can encompass everything that has happened to the bone and its specific context (Simpson 1963:24-25 in Lyman and O'Brian 1998:624). While the configurational properties of the past such as environments, species present, or behaviours change over time, "the physical, mechanical, and chemical principles by which alterations in bones and teeth are produced do not" (Shipman 1981b:360).

Neotaphonomic studies can be employed to identify and describe immanent properties of damage morphology and the processes that produce different patterns of damage morphology. This information can then be applied to archaeotaphonomic and palaeotaphonomic investigation using uniformitarian principles (Morlan 1984:160) or employed as tools to investigate configurational properties.

Shipman (1981a) suggested that Lyell's Uniformitarian principle, "the present is the key to the past" is the "first law of taphonomy" (Shipman 1981a:12). To complement this, the second law of taphonomy must be that "the occurrence of a past event can be deduced only by demonstrating that its effects differed from those of other, similar events" (Shipman 1981a:12). Features of damage morphology that are diagnostic of the causal component, but not of a specific actor or effector, can be a particular source of confusion in this regard. Such instances are examples of taphonomic equifinality. Taphonomic equifinality describes scenarios in which different taphonomic histories end in similar results (Lyman 2004). This is important to consider when attempting to differentiate between mark types and especially when examining and utilizing comparative, ethnographic, and experimental data.

Experimental studies of taphonomy and damage morphology provide the basis of accurate identification and comparison of tool marks and pseudo-tool marks in archaeology. Ethnoarchaeology and ethnographic analogy are linked to observational and experimental butchering studies. Ethnoarchaeology is the study of relationships between human behaviour and its material consequences in the present (O'Connell 1995:206) and is useful for the study of sources of bias in the archaeological record (Gifford 1980:105). These studies have been integral to the understanding and analysis of butchering processes, patterns, and their relation to tool marks.

The interpretive capacity and potential applicability of experimental archaeology and analogy were once hotly debated topics (Binford 1981a; Wylie 1985; Young 1989), a significant criticism being that it is clearly impossible to replicate completely the sets of variables affecting a particular artifact or ecofact. However, Young (1989) explained the value of experimental archaeology by suggesting that experimental replication allows us to understand better "the interplay of decision making, mechanical forces, and artifact morphology" (Young 1989:59). Through controlling as many of the known variables as possible in a given experiment (such as tool class and composition), we might produce results that are useful for making archaeological assumptions regarding scenarios that utilized similar forces to produce material culture.

The direct historical approach and ethnographic analogy provide frameworks for applying modern day experimental, ethnological, and ethnohistorical observations to zooarchaeological material. Employing principles of uniformitarianism, the direct historical approach dictates that observations made of extant cultural activities can be extrapolated back to past cultural activities, but also cautions that one must be aware of outside influences affecting the present observable group (Steward 1942).

An important theoretical concept behind taphonomic analysis is Schiffer's (1987:22) ideas of N-transforms (natural transformation processes) and C-transforms (cultural transformation processes). C-transforms, as applied to zooarchaeology, refer to all culturally derived processes affecting the bone, which may include everything from initial butchering and subsequent processing, to further modification and reuse. N-transforms refer to the non-cultural and environmental processes affecting the bone. N-transforms and trauma will be the source of the majority of pseudo-tool marks.

The distinction of C-transforms has been the source of some controversy as to whether specific C-transforms can be isolated from each other and from the cultural system as a whole (Binford 1981a:203). However, the C-transform concept is particularly applicable in the case of zooarchaeological analysis because specific tool marks will represent singular events; one cut mark represents one episode of contact between a tool and a bone. These single events can be reconstructed to form a clearer understanding of the series of events involved in the processing and disposal of the animal. Sometimes the various results of C-transforms and N-transforms will mask each other, which is why a clear understanding of potential taphonomic influences is important.

N-transforms offer less dubious territory in theoretical interpretation than C-transforms, but they are of no less significance to the history of a specimen. Marks derived from N-transform processes provide valuable contextual information that can often reflect the cultural system, such as instances of carnivore gnawing. It is important to note that cultural processes from different systems may contribute at different times to the same archaeological assemblage, and that the natural transformational processes interact with each other and with the cultural formation processes to create the complete taphonomic history.

C-transforms and N-transforms are concepts that contribute to the goal of behavioural archaeology, to “find the relationship between human behaviour and material culture” (Schiffer 1976:4). Zooarchaeological investigation of behaviour patterns utilizing cut marks is particularly amenable to this task. Besides behavioural archaeology, this thesis will employ the complementary theoretical perspectives of processual archaeology and middle range theory, and the sub-disciplines of ethnoarchaeology and experimental archaeology as well as uniformitarian concepts of the direct historical approach and analogy.

The processual approach with its concepts of scientific analysis and the desire to create universal criteria for human behaviours has spurred many ethnographic and archaeometric studies of taphonomy as well as the development of a host of morphological traits for the characterization of marks on bone. While processual principles are difficult to apply in terms of the interpretation of the complexity of a cultural system (especially one that is inherently unobservable like an archaeological system), they can and should be applied when producing archaeological data and undertaking data analysis. The importance of the use of the scientific method and repeatability and testability of research must be considered when undertaking any zooarchaeological analysis. Studies must endeavour to enable an ease of repeatability of their work by clearly describing methodology (indicating specific data used and how they were identified and analyzed) and employing scientific standards of identification and analysis. Since conclusions and interpretations will grow to be increasingly subjective as they become further removed from the data, it is essential that the data itself be as objective as possible.

3.2. Past Investigations of Tool Marks and Pseudo-Tool Marks

3.2.1. Tool marks in Zoo-, Ethno-, and Experimental Archaeology

Until the 1980s, many texts concerning zooarchaeology or zooarchaeological identification would neglect discussions of taphonomy. However, most current texts concerning zooarchaeology or faunal analysis will include sections on the subjects of natural and cultural bone modification and damage morphology (e.g. Binford 1981b; Bonnichsen and Will 1990; Reitz and Wing 1999:122-141; Hesse and Wapnish 1985:85-88; O'Connor 2000:19-27, 45-50), and texts concerning vertebrate taphonomy or taphonomy in archaeology will devote considerable space to them (e.g. Lyman 1994:294-402).

Several works have been put forward with the express purpose of summarizing zooarchaeological investigations within a sub-discipline of archaeology (such as historic archaeology) with attention to taphonomy (e.g. Jolley 1983; Landon 2005; Lyman

1977). Other comprehensive works include summaries of research in various topics including taphonomic investigations in zooarchaeology (e.g. Noe-Nygaard 1987; Fisher 1995), frameworks for taphonomic research (e.g. Lyman 1987; Denys et al. 1997), experimental taphonomic investigations in archaeology (e.g. Andrew 1995; Behrensmeyer 1978; Denys 2002), and compilations concerning bone modification (e.g. Bonnichsen and Sorg 1989). It is highly desirable that one or some of these references be consulted upon attempting a taphonomic investigation not only to provide the investigator with a clearer understanding of damage morphology and practices within the discipline but also to help establish an inter-subdiscipline standard of data collection.

The inclusion of data on tool mark observations is a relatively common feature of zooarchaeological investigations today, and so there are countless examples of the use of tool mark studies as part of broader faunal analyses on specific sites. However, there is a general lack of standardization regarding the actual data collected and the detail will tend to hinge on the interest and expertise of the observer. While many zooarchaeological studies from the various sub-disciplines of archaeology provide exemplary investigations of tool marks, a "more rigorous technical approach" (Jolley 1983:73) must still be advocated in all aspects of the discipline.

Since the 1960s, many studies from all over the world have included tool mark analysis as a component of the investigation of a particular site or site comparison (e.g. Alhaique et al. 2004; Frison 1970; Gilbert 1969; Johnson 1978; Landon 1996; Olsen 1978; Savage 1995; Todd et al. 1993). Cut marks studies also feature prominently in a wide range of zooarchaeological investigations covering a myriad of topics. These include broad issues such as early butchering and tool use or ethnicity vs. functionality in butchering patterns. More specific or regional topics such as early butchering in

Madagascar (Perez et al. 2005), tool marks on whale bones from Vancouver Island (Monks 2001), fur removal cut marks on bones from Mesolithic Denmark (Trolle-Lassen 1987), and everything can also employ cut marks studies.

Many other important zooarchaeological studies and site reports do not discuss pertinent taphonomic concerns or they may include limited taphonomic information but omit butchering marks as a complementary area of investigation. Commonly, a study might include presence/absence information regarding tool marks or other bone damage or may include some limited descriptive information, making interpretation, comparison, and verification or repetition of observations difficult if not impossible.

As with all practical zooarchaeological analyses, taphonomic investigations require comparative collections to be effective and thorough in terms of identification. Often individuals must create their own experimental examples to examine and compare to archaeological materials to provide a standard of scientific consistency (and the current study is no exception). Past experimental butchering studies employing traditional or experimentally produced tools have tested whether these data can provide analogies for archaeological butchering. These experiments have produced much of the data responsible for the current understanding of distribution and morphological traits of tool marks.

Walker and Long's (1977) inquiries into the morphological characteristics of tool marks, associated with their analysis on faunal materials from a Chumash site in California, was one of the first such experimental studies. This study filled an important void of the time by pursuing an objective investigation of butchering mark morphology and explicitly stating that butchering marks reflect the tool classes and specific tasks that made them (Walker and Long 1977:606). Walker and Long (1977) advocated the analysis of cross-sections of tool marks to compare different tool classes including unmodified, finely flaked, and coarsely flaked chert and obsidian tools, as well as metal tools.

Some of the first influential experimental studies of tool use, including the first applications of SEM to archaeological tool marks (Potts and Shipman 1981), were based on cut marked bones from at Olduvai Gorge. Investigations of early hominid sites (such as Olduvai or the Klasies River Mouth), have provided a wealth of information, speculation, and ongoing argument on early tool use and possible hunting and butchering practices (e.g. Bunn 1981, 1991; Bunn and Blumenschine 1987; Domínguez-Rodrigo 1997, 1999; Lyman 1987; Monahan 1999; Lupo and O'Connell 2002; Shipman 1986, 1987).

An important aspect of this significant body of work on tool use at early hominid sites is the investigation of the hunter vs. scavenger question. As a result, many studies concerned with the identification of cut marks vs. carnivore tooth marks (both macroscopically and microscopically), comparative damage morphology, and the establishment of morphological identification criteria for tool marks and pseudo-tool marks have been undertaken (Binford 1984; Blumenschine 1995; Bunn 1981; Bunn and Kroll 1986; Capaldo 1997; Lupo 1994; Selvaggio and Wilder 2001). Bunn (1991:447-452) discusses many of these, as does Haynes (2002). The FLK "Zinj" floor at Olduvai in particular has sparked massive amounts of research. Back and forth arguments, many surrounding research at FLK "Zinj" floor at Olduvai, have supported and refuted the usefulness of the application of cut mark distribution experiments to the past (e.g. Domínguez-Rodrigo 1997,1999; Monahan 1999) as well as the damage morphology and misidentification of different mark types (e.g. Blumenschine et al. 2007; Domínguez-Rodrigo and Barba 2006).

Ethnographic studies stem from experimental studies and provide much knowledge of butchering practices and patterns of recent hunting cultures, which can be compared to interpretations of frequency, distribution, and morphology of tool marks in archaeological contexts. Studies such as those done by Lupo (1994) and Lupo and O'Connell (2002) have focused on the frequency and distribution of butchering marks on hunted and scavenged bones, suggesting this relationship is not as clear cut as was once thought.

Archaeological remains from the Klasies River Mouth area were suggested by Binford (1984) to have been scavenged because their similarity in butchering pattern with patterns produced by the Nunamiut on frozen carcasses (Binford 1978). In warmer climes, such similarities have been taken to represent butchering of desiccated or scavenged remains (Lupo 1994:835). However, Lupo (1994) pointed out that the Hadza often butcher hunted animals after rigor mortis has set in and the resultant butchering pattern resembles that used on a frozen carcass.

Binford's (1978:47-61, 90-97, 142-144, 480) ethnoarchaeological investigations of the Nunamiut took particular care to note specific butchering practices. Experimental butchering investigations need not be ethnographic in nature; butchering experiments are also conducted in the lab setting. For example, butchering experiments carried out on fresh fish to test whether such activities produce cut marks suggest that cut marks on fish bones are grossly under-documented in the archaeological literature (Willis et al. 2008).

Several large-scale experimental investigations have been attempted with the purpose of observing natural modifications to bone collections in known locations and environments. This includes experiments such as Lotan's (2000) 3-year project studying the influence of natural conditions on exposed carcasses in Israel, Andrews and Armour-Chelu's (1998) 18 year investigation of surface exposed bones in Wales, and similar projects in Kenya (Behrensmeyer and Boaz 1980; Behrensmeyer et al. 2003). Another study, the Experimental Earthwork Project at Overton, spanned 32 years and featured multiple examples of artifact types buried in known depositional environments (Andrews 1995; Armour-Chelu and Andrews 1996). This experiment utilized the SEM to analyze the experimental cut marks and the natural surface modifications to both cooked and uncooked bones after decades of burial.

Other observational studies of natural bone modification include Hill's (1980) investigations of natural alterations to animal remains without human interference and Piper and O'Connor's (2001) investigation of urban small vertebrate remains. Other experimental studies of natural phenomena with the purpose of providing comparative data for archaeological studies (e.g. Andrews and Cook 1985; Blumenschine and Marean 1993; Watson and Abbey 1986) will be discussed in Chapter 3.2.2 while experimental studies employing the SEM will be discussed in Chapter 3.2.4.

3.2.2. Investigations of Natural Phenomena

Shipman (1981a) suggested that cut marks "can safely be assumed to be the work of hominids, using tools of stone, bone, shell, metal, or wood" (Shipman 1981a:108). This makes them an important candidate for use in the identification of hominid presence and activities. However, before anthropogenic modifications can be interpreted, they must first be distinguished from the myriad of potential natural taphonomic modifications that can serve to imitate or mask them.

Morlan (1984:162) stated explicitly that major forms of natural trauma including tooth marks, root etching, vascular grooves, trowel marks, and curatorial damage can be distinguished from tool marks. Marshall (1989:18) recognized four categories of animal modification (feeding, trampling, traumatic accidents, and behaviour) and five categories of physical modification ("air-wind-sun-rain-temperature", "water-ice", "gravity", "sediment-soil", and "other"). Taphonomic modifications can also result from combinations of these factors, such as in the case of bioturbation, in which organisms like burrowing rodents churn up sediments.

Palaeontological studies of taphonomy focus on taphonomic alterations on fossils, the majority of which are natural modifications (such as chewing marks, abrasion, and weathering), but can also include early cultural modifications. Information and techniques from these studies can be applied to investigations of recent materials but they hold the most bearing on early hominid sites and sites up to around 10,000 years of age such as early New World occupation sites, which require the extra factors surrounding fossilization to be considered in their taphonomic investigations. As mentioned in the previous section, an abundance of important taphonomic information has arisen from paleontological and palaeoanthropological investigations at sites like Olduvai Gorge.

The importance of identification of naturally derived marks on bone has been addressed by other disciplines as well. Several forensic investigations have been put forward regarding how to recognize natural trauma when interpreting human skeletal material (Haglund et al. 1988; Haglund 1992; Ubelaker and Adams 1995). These studies emphasized the importance of a familiarity with natural taphonomic factors and their effects, not only in terms of identifying potentially misleading bone trauma but also to aid in answering important questions regarding the antemortem, perimortem, and postmortem history of the remains.

Misinterpretations of natural modifications for cultural ones have been identified through re-examination of museum collections. For example, Haynes and Stanford's (1984) project found that only two of 25 fossil assemblages with previously identified butchering marks actually had evidence of utilization by early human occupants of North America. Horton and Wright (1981) re-investigated of the Lancefield bone bed in Australia and subsequently re-categorized the marks on the bones as deriving from carnivore and not human action. These and other diverse studies focus significantly on sources of error leading to misidentification of bone marks.

Attempts have been made to define criteria for the characterization of various types of natural damage morphology. Investigations of weathering in the 1970s include important research done by Miller (1975) and Behrensmeyer (1978). Behrensmeyer (1978) developed a system of identifying weathering stages now commonly used by zooarchaeologists. Under Behrensmeyer's (1978:151) six stage system for classifying weathering, deceptive weathering cracks can appear as early as stage 1 (stage 0 being a complete lack of weathering) and a weathering stage of 4 or higher will preclude positive identification of cut marks or mask them entirely. Cryoturbational processes such as freeze-thaw action (Marshall 1989:21) or wet-dry cycles contribute to the advanced weathering of bone surfaces.

Particle abrasion (Brain 1976) and trampling (Behrensmeyer et al. 1986) have caused many interpretive difficulties by both masking as well as mimicking true tool marks. Trampling experiments utilizing the SEM (discussed below) have attempted to define diagnostic criteria. Shipman and Rose's (1988:321-322) abrasion studies showed masking of cut marks but note that their abrasion experiments rarely produced large scratches and those that did would not mimic cut marks in a significant way. Oliver (1989) suggested that in cave scenarios, roof fall onto bones may cause tool mark mimics like "scrapes, slices, chop marks, and other linear abrasions that resemble marks made by stone tools" (Oliver 1989:83). This is described as a potential natural taphonomic factor, but has not been tested or investigated.

Fiorillo (1989:63) conducted experimental studies of trampling, which included partial skeletons of five cows being trampled by a herd of cattle. Shallow sets of subparallel scratches produced on many of the bones resulting from sand grains being pressed together by animal hooves (Fiorillo 1989:65). Fiorillo (1989:65) noted that hoof material is softer than bone and does not cut bone in lab experiments. This indicates that scratches could not be caused by hooves directly and would need the intermediary of mineral grains. The implications of this are that trampling marks should only be evident in environments containing sand grain sized sediments (Fiorillo 1989:66).

Fiorillo (1989:66) asserted that individual trampling marks can be indistinguishable from cut marks, even when viewed with the SEM, and suggested the use of macroscopic features and mark location as useful for distinguishing trampling from other mark types. Fiorillo (1989:Figure 9) recognized the variability of trampling mark morphology, even on a single element, in that they can appear as U-shaped or more V-shaped in cross-section, as linear or curvilinear, or as sets of very shallow scratches interspersed with deep scratches. While individual trampling marks may mimic cut marks, this wide morphological variability and the tendency for trampling action to produce many sets of marks, could be utilized as diagnostic features of trampled bone surfaces.

Taphonomic damage associated with alteration by living organisms is an important cause of pseudo-tool marks as well as cut marks masking surface damage. This can include invertebrate action (Andrews and Fernández-Jalvo 1997:199; Fejfar and Kaiser 2005; Gautier 1993) such as insect damage (Watson and Abbey 1986), plant action, microbial erosion (Blumenschine et al. 2007; Domínguez-Rodrigo and Barba 2006), and the actions of vertebrates.

Several documented cases of misidentified root etching exist, such as identified at the Jurgens site (Wheat 1979:137) or Binford's (1981b:49) criticisms of root-etched Acheulian "Arte Mobiliar". However, these are uncommon in current archaeology.

The effects of digestion by mammalian carnivores and raptors have been investigated by several researchers (Behrensmeyer 1978; Behrensmeyer et al. 1989; Fernández-Jalvo and Andrews 1992; Hill 1989; Klippel et al. 1987; Maguire et al. 1980; Sutcliffe 1970; etc.). However, tooth marks tend to be a more likely source of pseudo-cut marks.

The type and amount of damage an animal can inflict on bone reflects its tooth morphology, jaw mechanics, and relative strength (Berryman 2002:493; Haglund et al. 1988:986). Carnivore actions in particular have been the object of much literature although other vertebrates have also been found to be responsible for misleading marks. For example, several investigations of rodent gnawing have been undertaken (e.g. Klippel and Synstelien 2007; Miller 1975; Singer 1956:1133). In addition, bone and antler chewing behaviour has been observed in multiple ungulate species including domestic sheep (Brothwell 1976), and cows (Sutcliffe 1973), mule deer (Krausman and

Bissonette 1977), red deer (Kierdorf 1992, 1994), big horn sheep (Warrick and Krausman 1986; Keating 1990), caribou and reindeer, camels, and many African species including antelope, deer species, wildebeest, and giraffe (Sutcliffe 1973:429).

Many experimental investigations of carnivore alterations have been undertaken (e.g. Bonnichsen 1973; Sutcliffe 1970:112; Blumenschine and Marean 1993; Richardson 1980). There have been several attempts to identify carnivore taxa based on specific damage morphology (e.g. Domínguez-Rodrigo and Piqueras 2003; Haynes 1983; Pickering et al. 2008; Selvaggio and Wilder 2001). Several studies suggest that tooth pits can be used to identify the acting carnivore size or type that caused them (e.g. Andrews and Fernández-Jalvo 1997; Domínguez-Rodrigo and Piqueras 2003; Selvaggio and Wilder 2001). Haynes (1980, 1983) described suites of characteristics to identify different carnivore taxa based on bone damage. This more configurational approach is arguably a more useful avenue of investigation, especially considering that Domínguez-Rodrigo and Piqueras (2003) pointed out that, "[t]ooth marks alone cannot confidently be used to identify specific carnivore taxa in bone assemblages" (Domínguez-Rodrigo and Piqueras 2003:1387).

Some studies focus on comparisons between the activities of various specific carnivores (e.g. Andrews and Fernández-Jalvo 1997; Selvaggio and Wilder 2001). For example, Andrews and Fernández-Jalvo (1997:209) explained that since larger carnivores tend to have earlier access to carcasses than smaller carnivores and scavengers, the tooth marks found on the hind limbs in highest proportions are probably representative of the largest carnivore to utilize the carcass.

Early detailed carnivore studies focused primarily on African carnivores like hyenas (Sutcliffe 1970; Maguire et al. 1980) and large cats (Miller 1969; Bonnichsen

1973). Later studies included species of canids and bears (Binford 1981b; Eickhoff and Hermann 1985; Haynes 1983). Recently, Selvaggio and Wilder (2001) investigated bone modification by different carnivore taxa at Olduvai. Several studies employing the SEM provided more data on microscopic features of carnivore trauma (Potts and Shipman 1981; Shipman 1981b, 1983; Shipman and Rose 1983a). These will be examined further in Chapter 3.2.4.

3.2.3. Forensic Studies and Archaeological Studies of Human Bone

Extensive examinations of bone trauma and its causes have been undertaken by the fields of forensics, forensic archaeology and osteology, physical anthropology, and palaeoanthropology. These include a wide variety of investigations from studies of experimental trauma wounds to incidences of cannibalism (which may be the most closely related to zooarchaeological studies). In contrast to zooarchaeological studies, these studies are concerned specifically with damage to human remains and, in the case of forensics especially, violence and wrongful death. The mentality with which the material and problems are approached differs because the purpose tends towards discovery and explanation of violent trauma as cause of death as opposed to understanding butchering practices. Although cases of cannibalism or postmortem defleshing will somewhat reflect a butchering process, their causes and purpose invariably differ from what might be expected from an individual utilizing an animal.

Physical anthropological studies of archaeological human bone are the transitional link between archaeology and forensics and provide much of the referential overlap between the two specialties. Topics within this focus can include cannibalism, violence and warfare, mortuary practices (such as postmortem defleshing), and predation or scavenging of human remains by animals (Andrews and Fernández-Jalvo 1997).

While butchery studies are generally expressly concerned with postmortem bone trauma, forensic studies will also focus on the identification of antemortem and perimortem trauma (Lyman 1987:279). Several relevant guides to the identification of skeletal trauma and its assignment to antemortem, perimortem, or postmortem time frames have been published (e.g. Gruspier 1999; Micozzi 1986; Sauer 1998; Ubelaker and Adams 1995). Houck (1998:419-420) described criteria for categorizing bone trauma that included features only present on fresh bone such as periosteum shrinkage. Such criteria are not applicable to archaeological remains, but they do hold relevance when considering experimental marks on fresh bones.

Forensic studies are also afforded a greater degree of thoroughness in terms of their approach to tool marks than are zooarchaeological investigations due to the legal ramifications of their work. Forensic tool mark studies are desirable for comparison because they tend to explore tool marks in significant detail, have clear presentations of data used, corroborating case studies, and attempt to follow reproducible, scientific procedures. For example, Reichs (1998) outlined detailed procedures for investigation of postmortem dismemberment, which were primarily concerned with tool mark examination and relevant data collection.

Several edited volumes concerning forensics, forensic anthropology, forensic taphonomy, and forensic osteology have been put forward that incorporate studies of taphonomy and osteological trauma (e.g. Houck 1998:410-424; Haglund 1997:367-381; Reichs 1998:353-388; Sauer 1984:176-184, 1998:321-332; Schultz 1997:201-222; Smith et al. 2003:138-154; Stodder 2008:71-114; Symes et al. 1998:389-409, 2002:404-

434; Ubelaker 1997:77-90; Ubelaker and Smialek 2003:155-159). Several literature review articles concerning developments in trauma and tool mark analysis provide admirable background information (Nichols 1997, 2003; Springer 1995); however, these studies rarely incorporate information regarding archaeological or physical anthropological studies.

The Association of Firearm and Toolmark Examiners (AFTE) publishes a journal that has produced many pertinent studies of osteological modification (e.g. Biasotti and Murdock 1984; Kockel 1980; Miller 2000; Miller and McLean 1998) as well as the "AFTE Theory of Identification" which addresses several criticisms of the validity of forensic tool mark examination (Nichols 2007). There are also many discussions of specific forms of osteological trauma such as ballistic, blunt, and sharp force trauma (e.g. Bonte 1975; Houck 1998; Smith et al. 2003; Symes et al. 2002).

Sharp force trauma and knife related wounds are of particular interest to this thesis. Symes et al. (2002:406-407) explained that knife trauma can be classified as either knife-stab wounds or knife-cut (incised) wounds. This is an important differentiation when utilizing interdisciplinary terminology such as this. Knife-cut wounds are incised wounds that have greater length than depth. These marks occur "when a sharp-edged tool superficially incises bone while traversing over the surface of the bone" (Symes et al. 2002:407). These sorts of marks characterize butchering and dismemberment activities. This is in contrast to knife-stab wounds, known as sharp-force trauma wounds (often described as a "blunt force blow delivered with a sharp object" (Smith et al. 2003:148)), which will result in punctures or gouges when they contact the bone, and are more commonly related to cause of death.

The issue of weapon class must also be considered when utilizing forensic terminology. Houck (1998) explained that “a class is a group affiliation based upon common characteristics” (Houck 1998:412). While class characteristics can be numerous and specific, they are in contrast to individual characteristics, which are idiosyncrasies of a single specific tool.

Symes et al. (2002) clarified that the weapon class of knives can be distinguished from other forms of blades as they are “tools with a thin blade that sometimes terminates in a point” (Symes et al. 2002:407) and will “always have at least one area of edge bevel (sharpened edge) on the blade” (Symes et al. 2002:407). These characteristics clearly define a general class, distinct from tool classes such as saws, axes, and scrapers, however there is significant room for intra-class variation. Smith et al. (2003:149) describe six separate types of wounds produced in knife attacks including slash, stab, hack, flick, drag, and butt wounds, the first three of which, are likely to produce bone damage.

Like archaeological investigations, forensic case studies often include an experimental aspect or the production of a comparative sample. Forensics departments will also often maintain body farms as continuous experiments in body decomposition and alteration, which provides useful information regarding perthotaxic processes. Much like analyses of specific archaeological sites, forensic case studies also provide a venue for analysis of trauma and damage morphology (e.g. Symes et al. 2002; Sauer 1984, Frayer and Bridgens 1985; Ubelaker and Smialek 2003:155; Walsh-Haney 1999). Forensic case studies and experimental studies provide good supplemental information for archaeological and physical anthropological research especially in the area of tool mark identification.

While forensics provides a wealth of scientific examinations of bone trauma, forensic tool mark investigations are more practically applicable to historic zooarchaeology, as they primarily investigate firearm trauma and modern tool trauma such as saw marks (e.g. Symes et al.1998) or metal knife trauma (e.g. Houck 1988, 1998; Bartelink et al.2001). In addition, forensics will often concern itself with identification of specific tools or weapons (e.g. Houck 1998; Kockel 1980; Nichols 2007) when in the possession of potential candidates for the causes of individual marks, which tends to be an ineffectual line of inquiry within archaeology. A related criticism of forensic tool mark analysis is the problem of mistaking "sub-class" characteristics for individual characteristics (Nichols 2007:587). Arguably, the reverse is also a concern in archaeology, but mistaking individual or sub-class characteristics for more general diagnostic criteria can often be remedied with use of larger comparative samples.

Tool marks can reflect both mortuary practices (such as secondary burial procedures) as well as potential violent conflict. They can be used to differentiate between the two processes by examining tool mark type, frequency, distribution, and pattern (presence or absence) (Olsen and Shipman 1994:380). In her analysis of the Riviere aux Vase mortuary site in southeastern Michigan, Raemsch (1993) revealed the importance of thorough analysis of damage morphology, especially with regard to classification of mortuary behaviour vs. perimortem violence.

Distinguishing between cultural processes that can result in cut marks on bone is an important element of physical anthropological research. Cultural processes like violence, cannibalism, and mortuary practices are each characterized by certain features. For example, incidences of scalping are typically identified by the presence of multiple short, straight cut marks around the crown of the head (Olsen and Shipman 1994:384).

Multiple native groups throughout North America practiced secondary interment with attendant mortuary practices of flesh stripping and bone cleaning and washing (Raemsch 1993:229). Olsen and Shipman (1994) utilized the SEM to analyze cut marks on human skeletal remains in order to study conflict and secondary burial practices on the northern Plains. In this study, they describe common characteristics of marks associated with different processes such as defleshing and disarticulation, which are typically associated with secondary burial practices, and traumas such as scalping, blunt- or sharp-force trauma, trophy taking, and mutilation, which are all more commonly associated with violent conflict.

Olsen and Shipman (1994) described defleshing as "usually represented by short, fine cutmarks or broader scraping over the surfaces of bones caused when a sharp tool is used to remove soft tissue adhering to the bone" (Olsen and Shipman 1994:380). They also explained that "defleshing marks can occur anywhere on the bone" and "frequently appear in clusters, an indication that repeated strokes were necessary to successfully clean the bone" (Olsen and Shipman 1994:381). These can be similar to the filleting marks described by Olsen (1987) or Noe-Nygaard (1989) but, in contrast to defleshing marks, "filleting marks are usually concentrated on the points of origin and insertion of muscles and tendons" (Olsen and Shipman 1994:381). Cut marks located on or adjacent to articular surfaces suggest disarticulation activities (Olsen and Shipman 1994:381) both in scenarios of animal butchery as well as human burial practices.

Cannibalism may be associated with butchery-related cut marks, skeletal disarticulation, bone breakage, and burning whereas violence may be associated with limited trauma marks, and associated tool fragments such as projectile point tips (Turner 1983). Larsen (2002) noted that skeletal remains exhibiting "extensive diaphyseal fracture (for marrow extraction), cut marks at tendon and ligament attachment sites (for removal of flesh), and charring and blackening (from cooking over open fires)" (Larsen 2002:130) are common evidence of cannibalism.

Similarities between cannibalistic treatment of human remains and butchering of food animals (Novak and Kollmann 2000:72) are not surprising. Most studies infer cannibalism using the evidence of similarities with animal butchering marks (Villa et al. 1986). Edgar and Sciulli's (2006) agreed that there is a general resemblance in butchering pattern. However, at the Richards site they found butchering to be much more extensive for human remains than for animal remains, and significantly more so than was necessary or efficient for typical butchering processes (Edgar and Sciulli 2006:135). This suggests that the heightened cultural significance of cannibalism over animal butchery can be reflected in the tool mark patterning.

The SEM is often employed in investigations of trauma on human bone, more commonly than in zooarchaeological contexts, due to the greater thoroughness expected of such analyses and the heightened cultural relevance placed on their results. Applications of the SEM to tool marks on human bone will be discussed in the following section.

3.2.4. Applications of SEM

There have been multiple overviews of the applications of SEM to taphonomic and archaeological problems (Brothwell 1972; Cook 1986; Fisher 1995; Olsen 1988a; Shipman 1981b, 1988), all of which highlight the usefulness of SEM for examining cultural and natural bone modification. As Shipman (1981b) explained, the SEM offers “superior resolution of three-dimensional structures, greater depth of field, and the capability for higher magnification of specimens” (Shipman 1981b:360). These features allow SEM images to show much finer detail even at lower magnifications (Shipman 1981b:360) when compared to traditional light microscopy, which is limited in these areas as well as highly dependant on light source location for quality images.

Unfortunately, archaeological samples are often too valuable, fragile, or cumbersome to be directly examined using the SEM. This necessitates the production of moulds or replicas of the specimens, which can then be gold-coated and examined with the SEM. Methodology sections from many broader investigations often include descriptions of this process. Studies from several fields, including dentistry, have specifically addressed the issue of creating moulds and replicas for SEM examination (Scott 1982, Rose 1983).

Cook (1986) applied the SEM to investigate diagnostic criteria of various bone modification types and promoted the use of the SEM on museum collections. An advantage that Cook (1986) had in her investigations was the use of an SEM machine that was “fitted with a charge-free anticontamination system which, by using a differential vacuum across the aperture, enables uncoated specimens to be examined without charging” (Cook 1986:145). If such a system is available, it can be considerably advantageous “because it makes the work less expensive and time consuming and more generally applicable to the study of archaeological specimens which can be returned to museums unscathed” (Cook 1986:145). However, the size of the item being analyzed remains a limiting factor, and large specimens would still require the use of replicas.

Some debate has arisen in taphonomic studies regarding the necessity of the SEM to assessments of damage morphology. Several researchers (Binford 1981b;

Blumenschine et al. 1996; Blumenschine and Marean 1993; Oliver 1994) have argued that reliable identification of certain mark types can be accomplished without the aid of microscopy by examining macroscopically observable characteristics and employing a configurational approach. For example, Blumenschine et al. (1996) asserted that, with minimal training, damages like carnivore gnawing, chopping trauma, metal cut marks, and metal scraping marks can be distinguished from each other with a high degree of accuracy and precision.

Domínguez-Rodrigo et al. (2007:25) found that cut marks, percussion marks, tooth marks, and abrasion marks could usually be identified with low powered magnification. However, it should be noted that for their identifications Domínguez-Rodrigo et al. (2007) followed Bunn (1981) and Potts and Shipman (1981), both of which utilized the SEM to create their diagnostic cut mark criteria. Lewis (2008) discovered that sword and knife marks on bone could readily be differentiated from each other. However, it is probable that this case is at least partially related to the difference in how the weapons were used (hacking vs. stabbing).

Domínguez-Rodrigo et al. (2007) recognized the necessity of employing the SEM for questionable marks, but they concur with Bunn and Kroll (1986) that the application of the SEM to a large number of samples would be overly expensive, time consuming, and would not significantly alter the findings. Blumenschine et al. (1996:494) also cautioned against reliance on the SEM for several reasons including time and financial costs. Another concern is the tunnel vision of overreliance on micromorphological characteristics at the cost of contextual and macroscopic information (i.e. missing the forest for the trees). However, this can be circumvented by keeping a configurational approach in mind.

The SEM has been applied to many experimental studies of culturally and naturally derived marks on bone. These studies as well as their practical applications have provided important comparative images for use in other investigations, including the current research. Table 1 highlights some useful key sources of comparative images.

Table 1. Selected Published SEM Images of Tool Marks and Pseudo-Tool Marks

Taphonomic factor	**Reference**
Tool marks	Alhaique et al. 2004
Experimental natural marks & comparative tool marks	Andrews 1985:686-687
Trampling marks & comparative tool marks	Andrews & Cook 1985
Archaeological trampling marks & cut marks	Behrensmeyer et al. 1986
Percussion tool marks, cut marks, tooth marks	Blumenschine 1988
Experimental cut marks, directionality	Bromage and Boyde 1984
Archaeological cut marks on human bone	Bueschgen & Case 1996
Pseudo-tool marks & experimental tool marks	Cook 1986
Tooth marks	Domínguez-Rodrigo & Barba 2006:178
Archaeological cut marks	Domínguez-Rodrigo et al. 2005:115
Archaeological cut marks, directionality	Fernández-Jalvo et al. 1999:588
Trampling	Fiorillo 1989:67
Cut marks, pseudo-cut marks	Fisher 1995
Experimental & archaeological metal & stone cut marks	Greenfield 1999, 2000, 2002
Experimental stone tool cut mark	Haynes 2002:56
Tooth marks	Landt 2007
Experimental & archaeological tool & tooth marks	Potts & Shipman 1981
Archaeological cut marks and pseudo-cut marks	Oliver 1989
Experimental stone and metal tool marks	Olsen 1988b
Experimental trampling marks & tool marks	Olsen & Shipman 1988
Tool marks and pseudo tool marks	Shipman 1981b
Experimental stone & bone cut marks	Shipman & Rose 1983b
Experimental cut mark, vascular groove mark	Shipman & Rose 1984
Experimental and archaeological tool marks	Shipman et al. 1984
Cut marks on human bone, trowel trauma	Smith & Brickley 2004
Projectile point impact marks	Smith et al. 2007
Experimental cut marks made by shell knives	Toth & Woods 1989:252-253
Tool mark (micro, cross-section sketches)	Walker & Long 1977
Experimental stone and bamboo cut marks	West & Louys 2007

Culturally derived tool marks have been examined independently and with an eye to defining their various microscopic characteristics. For example, Smith et al. (2007) investigated the damage morphology of stone projectile point impacts on bone. Olsen and Shipman (1994) provided extensive descriptions of typical cut mark forms resulting from various postmortem activities, including defleshing, disarticulation, scalping, and other violent trauma. In addition, they promoted the utilization of the SEM to investigate and differentiate between various natural and cultural mark types.

The identification of stone vs. metal tool butchery has also been an important use of SEM in tool marks research. More commonly used to investigate the origins of metallurgy (Greenfield 1999) and Neolithic-Bronze Age-Iron Age transitions, it is also a key aspect of investigations of culture contact between stone and metal tool using groups. Since metal tools tend to be kept and curated much longer that stone tools, it is difficult to rely on the presence of metal artifacts as an indicator, as evinced by EfPm-27. These techniques can be used to help explain both butchering marks as well as manufacturing marks on bone artifacts (Olsen 1988b).

Walker and Long (1977) carried out the first major metal vs. stone cut marks study. Olsen (1988b) also applied the SEM to the metal vs. stone issue. Olsen (1988b) investigated various stone and metal tool type marks using the SEM, highlighting microscopic dissimilarities between major tool types used on bone artifacts.

Some of the most recent investigations into the origin of metallurgy have been carried out by Greenfield (1999, 2002), both experimentally and on archaeological materials. Greenfield's (1999, 2002, 2006) investigations of stone and metal cut marks focused on features for identifying material type and developed criteria that can be employed to this end.

Many studies have employed the SEM in experimental lithic modifications of bone to determine the possible differences in the morphology of marks left by stone tools of different compositions (e.g. Greenfield 2006; Stone 2006; Shipman and Rose 1983a; Walker and Long 1977). Stone (2006) asserted that diagnostic criteria could be developed, but it would require more research and a larger comparative sample. Shipman and Rose (1983a:66) found no clear dissimilarity between various material types (flint, chert, lava, obsidian, basalt, quartzite, and bone) as they all produced elongate grooves with fine striae. However, they did identify several distinct features of cut marks including shoulder effects and barbs. Greenfield (2006) found that "types of retouch and resharpening have a greater significance than raw material on cut mark morphology" (Greenfield 2006:155). He also discovered that, while the width and smoothness of the mark was related to the coarseness of the stone material, the magnitude of variables that must be considered make it "almost impossible to distinguish raw material purely on the basis of cut marks" (Greenfield 2006:155).

The SEM has been applied to considerations of alternatives to traditional stone and metal tools such as bone or shell tools. In their investigation of experimental bone and stone tool marks on bone, Shipman and Rose (1988:308) realized that bone tools could produce cuts that resemble stone tool marks albeit generally shallower and broader. However, stone tools tend to produce many more cut marks when compared to the number of cuts produce by bone tools performing identical processes. Shipman and Rose (1988) explained that this was "not an unexpected result, given that the obsidian flake was sharper, and therefore more capable of producing distinct marks, than bone flakes" (Shipman and Rose 1988:308). Shipman et al. (1984) also looked at bone tools using the SEM as did Runnings et al. (1989).

Toth and Woods (1989) conducted SEM analysis of experimental cut marks made with retouched mollusc shells. They (Toth and Woods 1989:253-254) demonstrated that some shell tools can produce cut marks that are morphologically identical to similar cut marks made by stone tools (including the production of narrow grooves with multiple striae) and would probably be characterized as such by most faunal analysts. In contrast to stone tools, the shell tools themselves are difficult to identify because the edge modification could be produced by common natural processes. These findings were echoed in Stevens and Wakely's (1993) similar investigation of mollusc shell cut marks. Choi and Driwantoro (2007) identified a characteristic "double track" appearance to shell tool cut marks that can be useful for identification.

West and Louys (2007) utilized the SEM to investigate experimental cut marks made with stone vs. bamboo tools. Distinguishing features of bamboo cut marks include an asymmetrical cross-section and "step-like series of striations on the shallow side of the cut mark" (West and Louys 2007:515). A configurational approach would also consider the potential availability of bamboo tools at the site.

Studies also extended to distinguishing natural damage from cultural modification on archaeological antler using the SEM (Olsen 1989). Olsen (1989:130) suggested that "marring" on antler (originating from a deer rubbing its antlers against hard surfaces to aid in the sloughing off of velvet) can mimic stone tool cut marks but will tend to be microscopically dissimilar as they "usually lack the fine parallel striae found along the walls of a groove formed by a flint tool" (Olsen 1989:130). In addition, like trampling, they will tend to occur in high numbers in a concentrated area (Olsen 1989:130-131).

Smith and Brickley's (2004) re-examination of tool marks with the SEM revealed flint tool cut marks and modern cutting trauma. One interesting mark showed the macroscopic characteristics of trowel trauma (a clean, V-shaped groove with irregular edges) but, when viewed using the SEM, it showed characteristics of having been made with a stone tool. This mark was deemed to resemble most closely a modern experimental stone tool mark, probably inflicted by one of the discoverers of the specimens. Smith and Brickley (2004:31) pointed out that a combination of the macroscopic and microscopic features was necessary to identify this mark. They also reiterate the usefulness of re-inspection of museum collections utilizing cut marks and the SEM as well as the importance of archaeologists being aware of and recording the traumas that they inflict on archaeological materials.

Shipman (1981b:358) also supported the application of the SEM to museum collections. The placement of archaeological specimens into museum collections opens them to a suite of related taphonomic alterations. Some studies have applied the SEM to investigations of trauma sustained during museum preparation. Fernández-Jalvo and Monfort (2008) used SEM analysis to evaluate preparation and preservation methods as taphonomic agents of museum collections. Several common museum techniques for processing fresh bone were evaluated including maceration in water, boiling, cleaning of bones by dermestid beetles, immersion in various forms of chemicals, enzymes, acids, putrefaction, and burial. Bromage (1984) experimentally abraded bone surfaces using various substances (particles, water, sliding, brushing, rubbing with fingers, exfoliation and chipping) and employed the SEM to analyze his findings. Of particular interest to this study are his findings that employing brushes to clean bone is known to smooth and abrade the bone surface. Behrensmeyer et al. (1986:769) also indicated that gentle washing of experimental cut marks has significant effects on their appearance.

The SEM has often been applied to palaeoanthropological issues of early butchery by hominids in Africa (Domínguez-Rodrigo et al. 2005). This has been primarily for conclusive identification of cut marks, which is especially important in cases of questionable association or lack of association with stone tools. However, the SEM has also been applied to issues of early butchery in regions all over the world. For example, Shipman et al. (1984) utilized the SEM in North America to identify butchering of Pleistocene mastodon bones from Michigan.

Gibert and Jimenez (1991) examined cut marks on lower Pleistocene fossils with the SEM. In their study, they observed that some marks that had been identified as cut marks lacked micro-striae within the groove. They (Gibert and Jimenez 1991) suggested that this may be due to several possible factors including weathering, idiosyncrasies of the cutting tool, the cutting action (such as force, angle, or motion), or "absorbing or dampening role of ligaments, tendons, and even the periosteum" (Gibert and Jimenez 1991:123).

A focus of much groundbreaking SEM research into tool marks has been on identification and characterization of early tool use. This includes a series of tool mark studies at Olduvai Gorge, which contribute to the significant body of work from the site (e.g. Bunn 1981; Potts and Shipman 1981; Fernández-Jalvo et al. 1999). Fernández-Jalvo et al. (1999:587) utilized the SEM on fossils from Olduvai to identify what are arguably the oldest cut marks on a small mammal fossil ever found. Potts and Shipman (1981:580) described the overlap relationships between carnivore gnaw marks and cutting marks on faunal materials from Olduvai Gorge and clearly illustrated the visual differences between the mark types using SEM images.

Shipman and her colleagues were pioneers of the application of SEM to archaeological problems at early hominid sites (e.g. Shipman and Rose 1983a, 1983b). This also included investigations into contrasting natural phenomena, such as trampling and particle abrasion (Olsen and Shipman 1988; Shipman and Rose 1983a), with cultural phenomena, as well as how pseudo-tool marks mimic tool marks. In addition, this research allowed for the production of methodologies for replicating archaeological samples for SEM examination (Rose 1983).

Shipman was not the only one to use the SEM to investigate the results of experimental and natural bone trampling (e.g. Andrews and Cook 1985; Behrensmeyer et al. 1986; Fiorillo 1989; Oliver 1994). Behrensmeyer et al. (1986) were the first to undertake a microscopic analysis of trampling vs. cut marks. Oliver (1994:93) experimentally identified the deceptive nature of pseudo-cut marks derived from trampling over coarse substrate and roof fall. However, Oliver (1994:93) also explained that the majority of such marks should not be mistaken for cut marks as they tend to be extremely shallow, display irregular groove edges, or be variable in appearance.

Andrews and Cook (1985) applied the SEM to the first experimental analysis of natural modifications of bone in a temperate setting. The majority of modifications observed were derived from trampling action on rocky substrate (Andrews and Cook 1985:689), and they note the high degree of variability in the micromorphology of trampling marks. Andrews and Cook (1985:688) recommended a holistic approach to the investigation of bone modifications involving SEM, microscopic, macroscopic, and contextual data (e.g. micromorphology, location, orientation, colour, dimensions, associations with breakage, general information regarding the assemblage and its context, etc.).

Alterations resulting from ingestion by humans and other animals have also been examined using the SEM. For example, Cook (1986:151) and Rensberger and Krentz (1988) have investigated the effects of digestion on bone using the SEM. Blumenschine and Selvaggio (1988:763) utilized the SEM to analyze experimental percussion marks in order to distinguish them from carnivore tooth marks. Landt (2007) employed the SEM to investigate human tooth marks on small mammals. Pickering and Wallis (1997) examined experimental chimpanzee tooth marks using the SEM. Pickering and Wallis (1997:1124) recommended a more configurational approach as they found that chimpanzee bone gnawing cannot be differentiated from carnivore gnawing microscopically.

As mentioned in the previous section, the SEM has been used for investigations of tool marks on archaeological human bone associated with violence, cannibalism, and mortuary practices. Archaeological investigations of historic warfare utilize trauma analysis extensively and commonly employ the SEM (e.g. Mitchell et al. 2006; Hutchinson 1996; etc.). For example, the SEM has been employed in the investigation of scalping such as in the case of the Vosberg site in Central Arizona. These marks were analyzed in a similar manner to the present study utilizing SEM on negative impressions of the cut marks (Bueschgen and Case 1996).

Villa et al. (1986:434-435) utilized the SEM and a random sampling strategy as a check on macroscopically identified cut marks on human bone. White (1986) utilized the SEM with Rose’s (1983) replication technique to aid in the identification of defleshing cut marks on the Bodo cranium from Ethiopia , probably the earliest solid evidence of intentional hominid defleshing. Conversely, Russell and LeMort's (1986) examination of the Engis 2 calvaria identified potential scalping cut marks and suggested use of the SEM was necessary. White and Toth's (1989) re-examination of the Engis 2 marks using the SEM found that they were in actuality several forms of preparation damage and further point out the same for the example specimens used in the original investigation (White and Toth 1989:367). White and Toth (1989:367) noted characteristic laboratory trauma on the Engis 2 cranium resulting from "sandpaper striae formed during the restoration of the vault[...], molding striae formed when mold part lines were incised into the fossil, and profiling striae formed when craniograms were made with sharp steel instrument tips".

Eickhoff and Herrman's (1985) study of human bone remains from a Neolithic collective grave site focused on an examination and comparison of experimental carnivore chewing marks to the archaeological remains, concluding that carnivores were probably responsible for the marks. Further they investigated and criticized some of the previously developed criteria (e.g. Shipman and Rose 1983a) for distinguishing these mark types.

Hogue (2006) carried out a study that was similar in essence to the present study. In it, scalping cut marks on human crania from a Protohistoric site in Mississippi were analyzed for tool composition utilizing the SEM and found to have been most likely the product of stone tools. Hogue (2006) noted that, "continued use of traditional materials is particularly interesting given the historical documentation of European knives in the region during the15th and 16th centuries" (Hogue 2006:247).

A case of scalping on a Neolithic cranium from Sweden also showed similar cut marks (During and Nilsson 1991). In a pilot study, these cut marks were analyzed utilizing a stylus instrument that moved across the bone surface. These movements were recorded and used to produce 3D models of the cut marks. The resolution of these models was related to the number of passes the stylus made across the cut mark. These data were contrasted with traditional SEM analysis. The proposed method shows great promise especially with regard to providing information as to the depth and cross-section of cut marks that can be easily evaluated statistically. However, it does require specialized equipment and its results are significantly lacking in the qualitative information provided by high quality SEM images and may rely too heavily on cross-sectional information for identification.

The SEM is often applied to modern human bone in forensic contexts (Schultz 1997; Olsen and Shipman 1994) and in experimental forensic investigations. For example, Bartelink et al. (2001) examined the quantitative characteristics of sharp force trauma utilizing the SEM on experimental fine metal cut marks. A series of experimental analyses were carried out on hacking trauma with various tools utilizing features visible macroscopically (Humphrey and Hutchinson 2001) and microscopically (Tucker et al. 2001) as well as using the SEM (Alunni-Perret et al. 2005). Houck (1988) utilized the SEM on metal cut marks to investigate the potential for the identification of individual characteristics. Bromage and Boyde (1984) used the SEM to attempt to identify features that could be used to determine the specific directionality of a cut mark.

It is clear that the SEM has been useful for the identification of pseudo-tool marks and tool-marks in many different scenarios. It has been especially recommended for use in several key circumstances including re-examinations of museum collections, as a check on macroscopic identifications, experimental studies requiring fine detail, forensics, and cases of early tool use or in metallurgically transitional periods due to the potential for poor association with archaeological tools and the presence of macroscopically deceptive mark forms. However, it is also necessary to employ as much macroscopic and contextual information as possible for a complete analysis.

Chapter 4

Approaches to Identification and Analysis

4.1. Identification and Categorization of a Mark

In order to yield a full identification and analysis of a mark on a bone, one must address several general problems. It must be determined whether the mark in question has resulted from cultural processes or natural processes, the time frame of its origin (whether it is archaeological, post-depositional, or recent), as well as the ultimate cause of the mark should be determined as specifically as possible. Questions concerning the specific causal activity resulting in the mark and its potential taphonomic and cultural significance can then be considered within a logical context.

Figure 4 depicts a guide for categorization of a mark on an archaeological bone. One might address this problem as identifying increasing levels of specificity of classification based on the available relevant information. One should approach this with a configurational analysis view in mind for a more holistic interpretation.

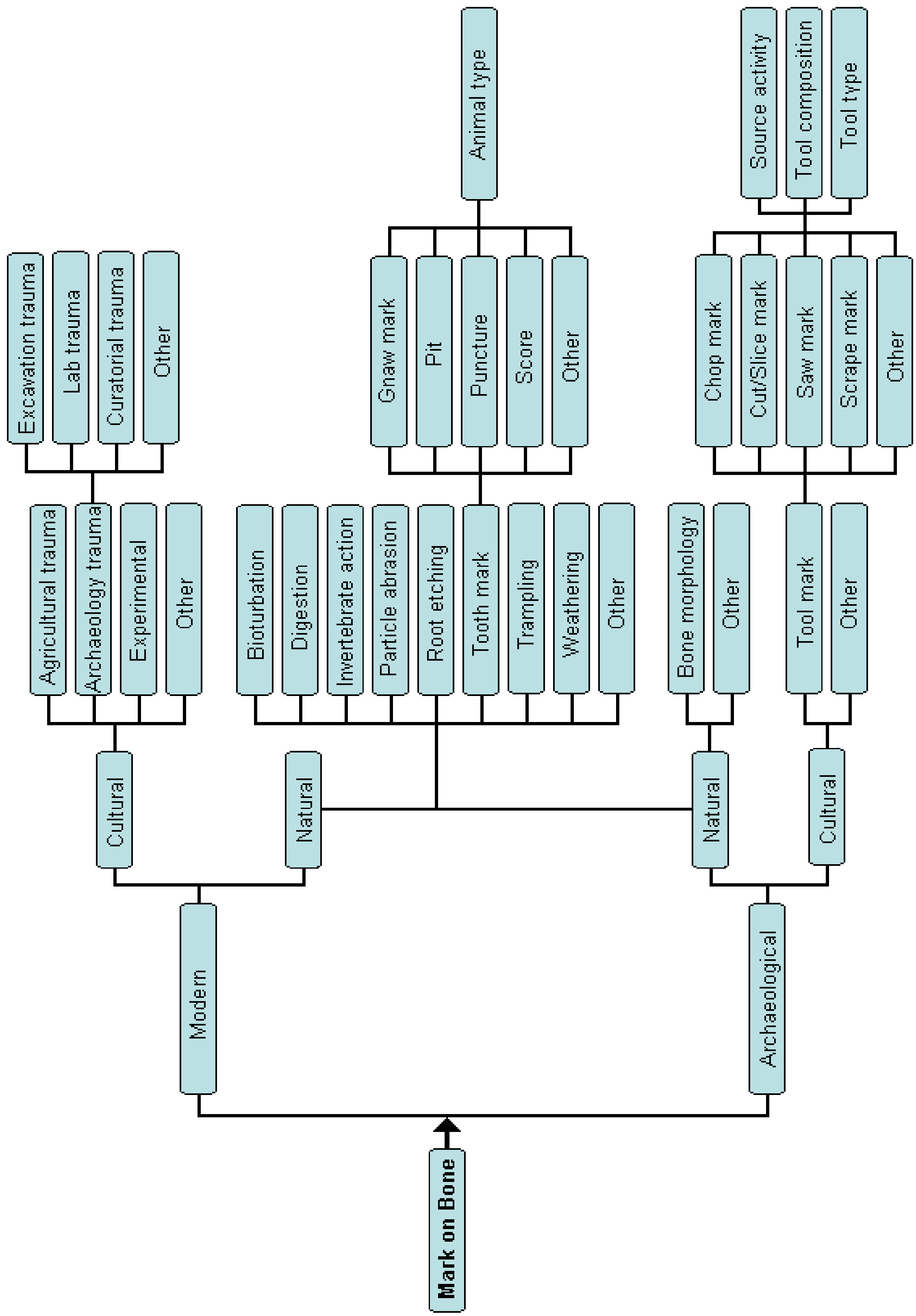

Figure 4. Decision tree for identification of a mark on archaeological bone.

Of primary concern is distinguishing between a modern vs. an archaeological original time frame. Observations made during excavation and retrieval are invaluable for this step, and will often be the clearest evidence available to differentiate between the two, especially in the case of natural modifications. For example, bones found on the surface will be more likely to have recent weathering or natural modifications by animals, the presence of live roots attached to the specimen will indicate root etching, and damage that occurs during excavation or cleaning may be recorded so as not to be confused with archaeologically significant modifications. If the mark is recent or post-depositional it may still provide valuable information as to the depositional environment, potential disturbances that may have occurred, or other archaeological and non-archaeological factors which may have affected the specimen and the archaeological site after its initial use.

Identification of the mark's origin as cultural or natural is another key step. Many natural taphonomic processes (e.g. animal or plant action, trampling and particle abrasion, weathering, etc.) as well as modern human action (e.g. damage derived from agriculture, construction, the actions of archaeologists, etc.) can cause marks that may resemble butchering marks in some respect. In many cases, such pseudo-tool marks can be identified with simple naked eye or hand lens inspection of the damage morphology and the consideration of excavation and post-excavation documentation various contextual mitigating factors.

Once an archaeological tool mark has been identified, it must be classified as to the probable form and composition of the tool that produced it and the likely action that was taken to cause the damage. There are four general morphological classifications of tool marks reflecting the most common tool classes and usages at butchering sites. These are slicing, scraping, sawing, or chopping marks.

Examining the kerf of a tool mark provides important information regarding the mark's origin. The kerf is the groove or notch made by a cutting tool, saw, or axe. Lewis (2008:supplement) defined this more explicitly by differentiating between the kerf, the walls, and the sides of a cut mark. He uses these terms to refer to the floor of the groove, the exposed damaged bone between the kerf and the sides, and the exterior bone surface adjacent to the groove respectively. The term "kerf" has also been defined in a general sense referring to a cut mark in its entirety, including both floor and walls, or may even be used to refer to the width of the groove. Although it may be redundant, the term "kerf floor" and "kerf sides" will be used herein to refer specifically to these portions of the mark and the term "kerf" will be applied in its more general sense. Besides the appearance of the walls of the kerf, characteristic data describing the kerf include its length, width, depth, shape, colour, and consistency.

Slicing activities produce cut marks that represent knife use and contact with the bone during butchering. Cut marks will often be variable in form along their length due to differential taphonomic factors, both in terms of their production as well as subsequent modifications. Therefore, it is necessary to examine the entire length of the cut, both macroscopically and microscopically.

Once cut marks have been identified, it is desirable that they are catalogued and their locations and other relevant information be individually sketched and recorded in a testable and repeatable manner. This will allow for a more thorough analysis of archaeological faunal materials and greater ease of comparison between studies. For example, Lewis (2008:supplement) suggested eight categories of information that should be recorded when describing the gross characteristics of a tool mark. These include length and shape but also include flaking, feathering, cracking, breakage, and shard presence, and aspect (Table 2). All of these features should be examined using multiple levels of magnification.

Table 2. Tool Mark Characteristics

Characteristic	**Description**
Length	Straight distance between far ends of mark
Shape	Outline of mark including associated removed bone (e.g. Line, circle, ellipse, triangle, parallelogram, pentagon, etc.)
Flaking	Removal of flakes from sides of mark (e.g. Unilateral, bilateral, absent)
Feathering[a], adhering flakes[b], or peeling damage[b]	Raising or pulling away of sides of mark; can be flake-like but is still attached to main bone
Cracking[a] or incipient fracture cracks[c]	Cracks associated with the mark
Breakage	Bone breakage associated with the cut mark
Shard Presence	Bone fragments within the groove
Aspect[d]	Perpendicular (90 – 46 degrees); Glancing (45 – 0 degrees)

Note: According to Lewis' (2008) criteria unless otherwise specified.
[a]Lewis 2008
[b]White 1992:140
[c]White 1992:137-138
[d]Humphrey and Hutchinson 2001: 229

Some researchers also utilize cross-section morphology as part of their identification data. In their study of cut marks on lower Pleistocene fossils, Gibert and Jimenez (1991:125) observed that cross-sectional shape is too variable to be considered a diagnostic feature. Walker and Long (1977:616) found that a single tool could produce a wide variety of cross-sectional forms when different pressures were applied when producing experimental marks. However, both Greenfield (1999) and Walker and Long (1977) found cross-sectional analysis useful for differentiating between morphologically dissimilar blade types, such as serrated metal knives, saws, and stone tools.

Guilday et al. (1962:63) required that butchering marks appear in a repeated pattern with some anatomically dictated purpose in order to qualify as such. Lyman (1987:260) has labelled these criteria as “redundancy” and “purposiveness”. However, he cautions that, while these criteria are important for characterizing butchering patterns, natural phenomena can also create or mask redundancy and the presence or absence of identifiable purposiveness does not necessarily indicate that the mark was or was not created by humans. However, overabundance on the bone and/or in the assemblage and randomness of placement must be considered suspicious and probably indicative alternate sources.

One must also consider the mark’s position on the bone and any associated marks or breakage, which may indicate the causal butchering process. However, caution must be used because breakage points are also a common point of attack for carnivores and rodents. In addition, there is potential for non-cultural sources of trauma causing deceptive bone breakage.

Unlike cut marks, pseudo-cut marks may be present on any bone at any location. Cut marks on an animal are determined by cultural and anatomical factors that reflect the butchering patterns such as skinning, segmentation of carcass into butchering units, defleshing, or further processing as well as the removal of desired products from the animal. This is illustrated by cut marks on the hyoid bones suggesting tongue removal, at the articular surfaces of bones where disarticulation is easier, and in areas like the distal ends of limbs where the bone is close to the skin reflecting hide removal. Similarly, anatomical considerations give information as to the likelihood of a cut mark appearing in a certain location. If the surface in question was relatively inaccessible, it is less likely to hold a cut mark.

The site type, context, and relevant related artifacts will imply information about the purpose and causes of tool marks or will suggest what sorts of marks one is likely to find. A kill site suggests cut marks may be found in locations serving a primary butchering purpose. The presence of certain tool types or materials suggests they may have been responsible for any cut marks, although a lack of other artifact types does not necessarily indicate that they were not present or utilized there. For example, an abundance of stone tools at a kill site suggests the possibility that the majority of cut marks were produced with stone tools; however, this does not rule out the use of metal tools if the site is Protohistoric or later. It is important to use multiple lines of evidence to interpret all aspects of the assemblage and obtain as much information as possible.

It is also important to recognize the condition of the bone itself. Even if the surface appears intact the external surface may have exfoliated, flaked off, or been otherwise damaged. If the original surface is no longer present or is otherwise damaged it will not reveal surficial cut marks (Fisher 1995:32). An intact surface is a better location to find true cut marks. Arguably, the bottom of the kerf of deep marks could remain even if the bone surface is damaged. Such marks might retain some of the features and characteristics of cut marks even if they themselves have been subject to trauma. However, this often results in many potential cut marks becoming morphologically inconclusive. In addition, there comes a point when marks on bone cease to be potential cut marks and become damaged bone surface and trauma.

Figure 5 shows an example of pseudo-cut marks that can be characterized as such using multiple lines of evidence. Observations regarding the condition of the bone, the mark frequency, location, orientation, colour, and macroscopic morphology all contribute to a more correct and specific identification of a mark's origin. Table 3 addresses some of the key lines of evidence to consider for this specimen.

Figure 5. Macroscopic image of Cat#256 showing marks on dorso-cranial surface of thoracic vertebra. Refer to Table 3 for description of identification.

Table 3. Multiple Lines of Evidence for Pseudo-Cut Marks on Cat#259

Characteristic	Description of Cat#259 (Figure 5)
Bone surface condition	Worn appearance, exposed spongy bone, and absence of visible articular facets that should be present at this location are evidence that the original bone surface is no longer present
Mark location	Location of the marks is irregular compared to the rest of the assemblage. The surface would be relatively inaccessible anatomically during primary butchering as the majority of the marked area would have been in contact with the caudal articular facets of the preceding thoracic vertebrae
Colour	Colour of the marks is dissimilar from the surrounding bone surface, which is an anomalous feature and characteristic of trauma
Frequency and orientation	Number and orientation of the marks implies they would have be made with a repeated, back-and-forth motion atypical of what one might expect during butchery but observable in archaeologists as they trowel through thick soils and roots
Mark morphology	The marks themselves are of dissimilar morphology to cut marks both microscopically and macroscopically

The consideration of multiple factors including microscopic and macroscopic features, position, orientation, frequency, site context, depositional contact, and external variables, a combination of the “physical approach” and the “configurational approach” provides a much stronger argument than would be gleaned from relying on any single factor. For example, one might assume that gnaw marks on bones are attributable to animals that are historically likely to have been present at a site. However, it is important to weigh the interpretive value of each of the variables being employed. Shipman (1981b:365) emphasized that “only *distinctive* attributes of the damage or alteration can be considered diagnostic, since many events may produce grossly similar results”.

There are few diagnostic single features, but if a configurational approach is applied, a suite of characteristics that are typical of a particular mark type can be used for identification. A mark’s location, angle of orientation, frequency, and associations provide important contextual information that can aid in identification and interpretation (e.g. Blumenschine et al. 1996; Blumenschine and Selvaggio 1991; Bunn 1981; 1991; Capaldo 1997; Gifford-Gonzalez 1991; Olsen and Shipman 1988; Selvaggio 1994; White 1992). Especially in the case of complex assemblages where multiple masking factors and high potential for pseudo-cut marks are present (e.g. Pickering et al. 2008:34), a configurational approach provides a wider basis of evidence from which to draw.

The causal component of slicing cut marks made by stone tools is shared by several other actor/effector interactions (such as trampling or rock fall). This results in the appearance of taphonomic equifinality if a purely physical approach is pursued on single marks. However, when multiple marks and their patterns are considered, suites of defining characteristics can be seen which are less likely to have overlap between actor-effector combinations of the same causal component. The perception of taphonomic equifinality can be related to the intensity of the examination. As Bonnichsen (1973:27) noted, the more characteristics that are considered the more reliable the identification becomes.

4.2. Tool Mark Morphology

Tool marks must be investigated for both tool class and tool composition. As previously mentioned, tool marks related to butchering can usually be categorized into four general morphological types including slicing, scraping, sawing, and chopping marks. These four types are associated with how a tool was used on the bone and the probable tool class or form that made it; they can be differentiated based on their gross morphological characteristics (Table 4).

Chop and impact marks result from blows from a chopper or blade such as a cleaver, axe, or hammer (Figures 6 and 7). Blumenschine and Selvaggio (1988:763) described percussion marks as “pits or grooves impressed on a bone’s surface by natural protrusions on the granitic hammerstone and anvil used” that are characterized by association with hammerstone impact notches and patches of microstriations (usually visible macroscopically) (Blumenschine and Selvaggio 1988:763). Noe-Nygaard (1989:473) characterized the kerf of chop marks as having “the form of a tilted «V» where one leg is broken off half way up” and the longest wall as having “smooth or fine striations parallel to the chop direction”.

Table 4. Morphology of Tool Marks

Mark type	Location (typically)	Cross-section	Form	Cause(s)
Slicing	Joints and other areas significant to killing, butchering and processing.	V-shaped to U-shaped in cross-section (depending on tool used), multiple fine striations in main groove parallel to slicing direction	Long grooves	Blade drawn across bone parallel to long axis of blade.
Sawing		Square shape, parallel striations on bottom and sides of groove, top edges may have chipping/crumbling	Often series of parallel grooves	Multi-toothed blade drawn across bone
Chopping	Dependant on butchering units and tools used by a culture.	V-shaped and broad. Bone fragments crushed in wards.	Elongate ovals or grooves	Impact of blade on bone
Scraping		Broad with no nadir/main groove, often striations. Or multiple fine parallel striations.	Broad area with striations depressed below bone surface. Chatter-marks may be present.	Made by blade drawn across bone perpendicular to long axis of blade

Note: Developed from Shipman (1981b), Olsen (1988a), and Binford (1981b).

Figure 6. Macroscopic image of Cat#584: tibia shaft with multiple overlapping impact marks, associated spiral fracture, and split-line cracks.

Figure 7. Macroscopic image of Cat#339: thoracic vertebra with lens-shaped impact mark.

Blumenschine and Selvaggio (1988:764) explained that percussion microstriations differ from stone cut marks “in being shallower, narrower, and usually shorter and occurring in dense unidirectional patches”. They also differ from scraping marks, “which are substantially longer and are oriented within 15º of parallel to the bones long axis” and from trample marks, “which are usually longer and uniform and/or predictable directionality” (Blumenschine and Selvaggio 1988:764).

Chop marks and impact marks will have crushing damage, collapsed bone, and bone fragments within the groove. The breadth and depth of the mark will depend on the tool type and number of blows. Lewis’s (2008) investigation of the sharp impact marks of various sword types suggested that diverse blade types are distinguishable from each other by such marks. Impacts on bone tend to be associated with segmentation of the carcass or breaking open bones for marrow processing (Noe-Nygaard 1989:473).

Impact marks can also include projectile wounds. Smith et al. (2007) found that stone projectile point wounds often show the internal parallel striations found in stone tool cut marks. Other identifiers included broken arrow fragments in the wound and internal bevelling (a general characteristic of projectile wounds such as gun shot wounds).

Saw marks result from a multi-toothed blade being drawn back and forth across the bone (Figure 8). This type of mark includes two perpendicular fields of directionality, that of the individual blade stroke and that of overall saw progress through an object (Symes et al. 1998:398). Blade progress is marked by distinctive features such as false starts and initial corners of the kerf and a break-away spur or notch at the end point (Reichs 1998; Symes et al. 1998). These features are not always present, but cross-section striae, indicating blade stroke, are a universal feature of sawed surfaces (Figure 8).

Saw marks from toothed metal saws are common, almost ubiquitous, in historic sites. Saw marks from stone tools, as opposed to metal saws, are described by Noe-Nygaard (1989:473) as having “terraced walls with crossing striae in the longitudinal direction and a broad uneven bottom trace” and are often found at attachment areas for tendons at “complicated closed joints” and tarsals at deliberately prepared breakage points.

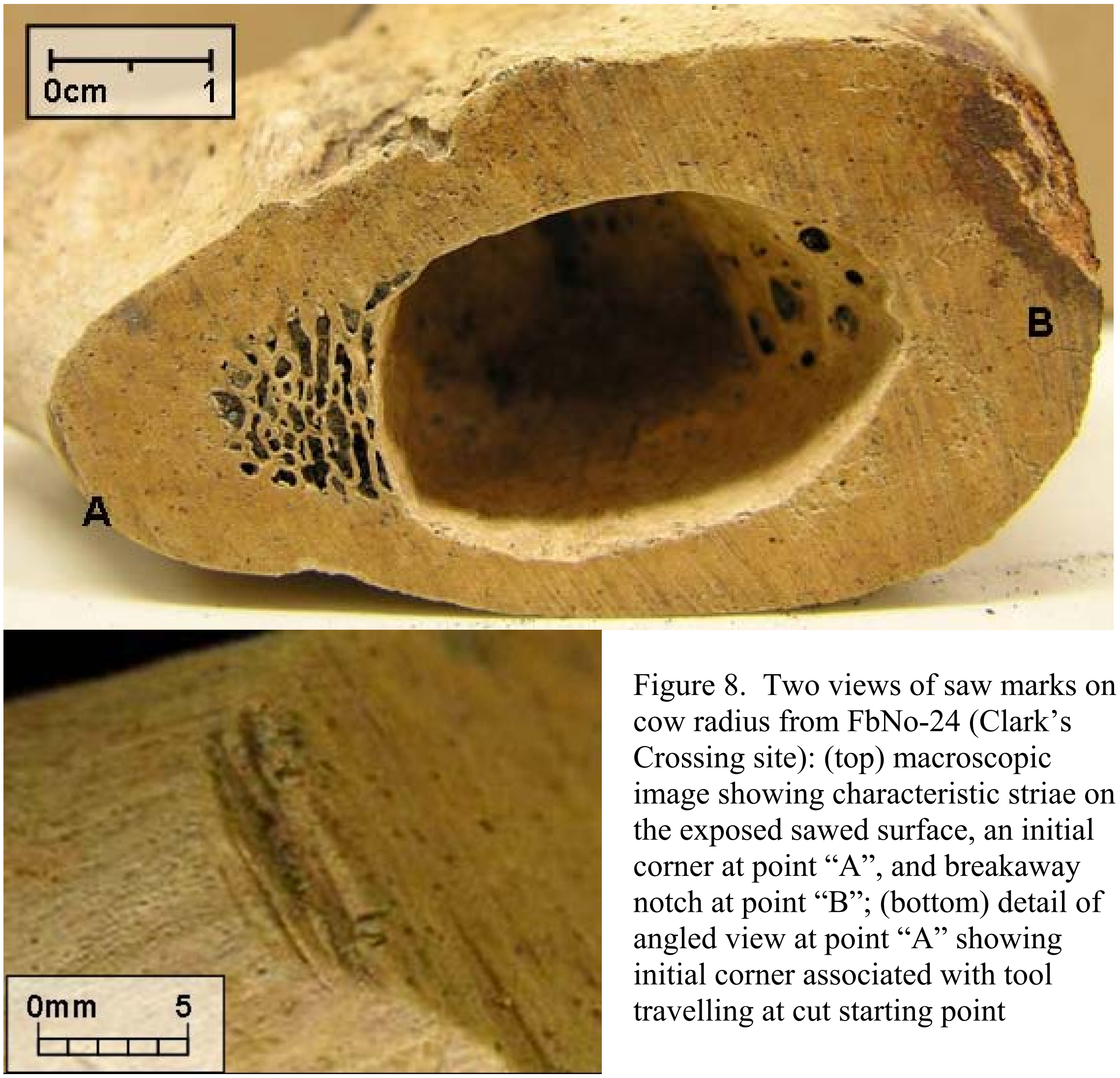

Figure 8. Two views of saw marks on cow radius from FbNo-24 (Clark's Crossing site): (top) macroscopic image showing characteristic striae on the exposed sawed surface, an initial corner at point "A", and breakaway notch at point "B"; (bottom) detail of angled view at point "A" showing initial corner associated with tool travelling at cut starting point

Scraping marks result from the edge of a tool such as a knife or scraper, being drawn across the bone, in a direction perpendicular to the long axis of the tool edge. These are characterized by multiple, fine, shallow, parallel scratches (Figure 9). Imperfections such as nicks or projections in the blade surface create irregularities in the series of striae. Scrape marks may cover relatively large surface areas compared to other mark types and may be associated with "micro chop marks" resulting from the blade losing contact with the bone surface (Noe-Nygaard 1989:472). Noe-Nygaard

(1989:472) attributed scrape marks to the "removal of meat by filleting" and described them as "a series of shallow subparallel, smooth walled grooves". Binford (1981b:135) noted that scrape marks on bone may be associated with the removal of the periosteum.

Figure 9. Macroscopic image of Cat#323: thoracic vertebra showing scraping marks of indeterminate origin on base of spinous process.

Scraping marks are the most commonly mimicked mark type (Shipman 1988:266). They can be highly deceptive, as their characteristics are closely resembled by concentrations of pseudo-cut marks produced by several common processes like trampling and particle abrasion. However, it has been suggested that the presence of “chattermarks” can distinguish them from mark forms like trampling (Shipman 1988:266; Olsen and Shipman 1988:546). Olsen (1988a) noted that “chattermarks” could also be associated with excessive pressure being applied to the tool, causing the edge to dig into the bone.

Stevens and Wakely (1993) suggested that chatter marks in shell scrapes are related to uneven movements of the tool across the bone surface. This could be associated with the actions of the butcher or features of the tool, such as its fragility, causing irregular starts and stops.

Slicing marks originate from thin blades like knives being drawn across the bone parallel to the long axis of the blade. Typically, cut marks are described as being relatively long, narrow, linear striations with a U- to V-shaped cross-section (Noe-Nygaard 1989:471). As previously mentioned in Chapter 4.1, cross-sectional morphology may be useful as a general characteristic of cut marks or dissimilar blade types, but is too variable to be considered diagnostic. Figures 10 and 11 both depict stone tool cut marks as verified by SEM, but magnified images suggest that their cross-sections are macroscopically dissimilar (more U-shaped and V-shaped respectively).

The location of cut marks also reflects the actions of the butcher. Repeated actions can result in a pattern of cut marks in the same location on different specimens, multiple parallel cut marks in the same location (Figure 11), or cut marks illustrative of continuous action across multiple articulating elements (Figures 10 and 12). A continuous tool mark across multiple elements can also be found in other forms of tool marks, especially in the case of saw cuts.

Figure 10. Two views of Cat#402 (cranial) & 403 (caudal): (top) macroscopic image of articulating thoracic vertebrae showing associated cut marks crossing multiple elements; (bottom) microscopic image of cut mark on Cat#403 showing U-shaped appearance of kerf.

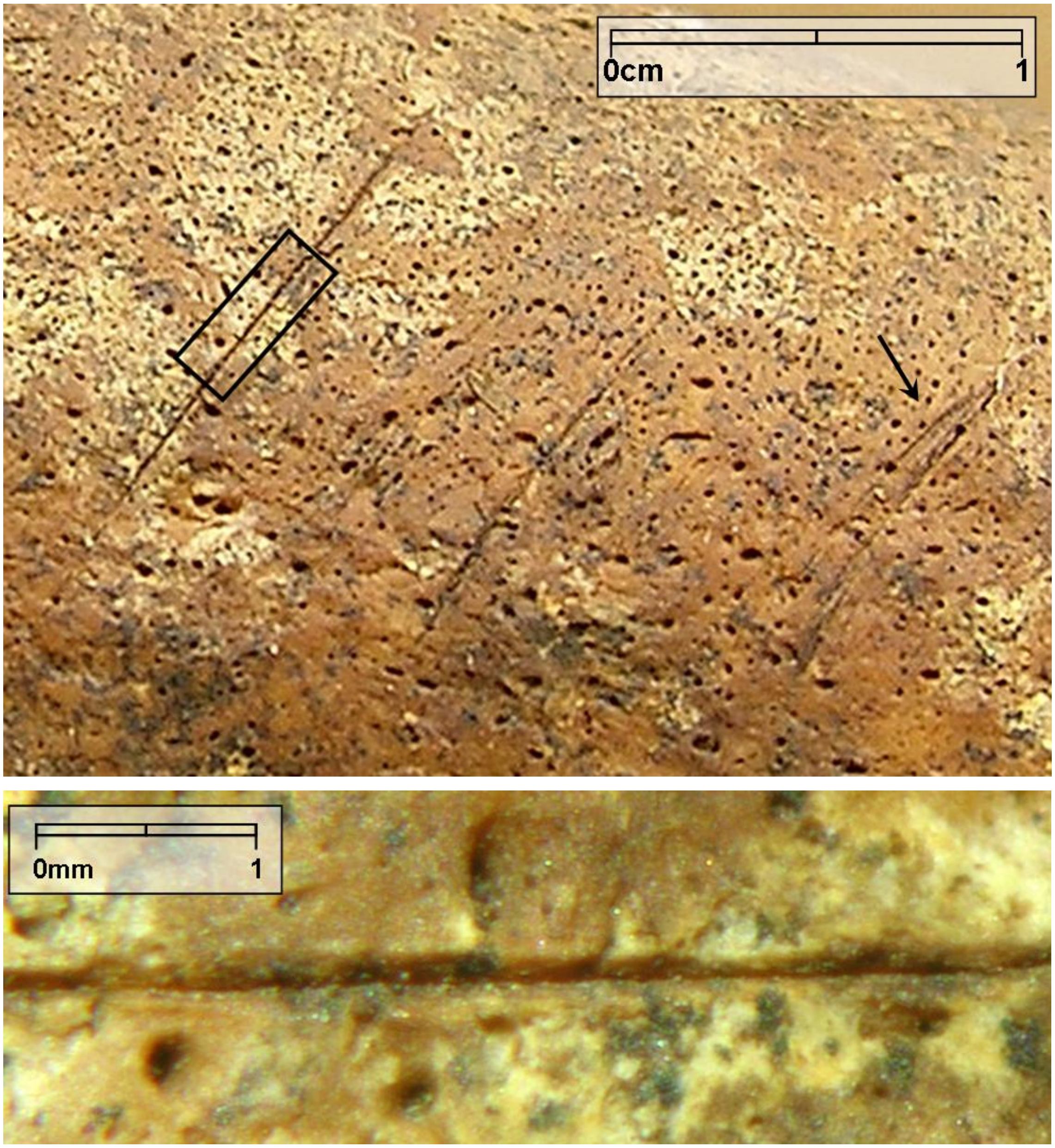

Figure 11. Two views of cut marks on Cat#604: (top) macroscopic image of metatarsal shaft with multiple cut marks, arrow indicates cut mark with shoulder effect, rectangle highlights location of bottom image; (bottom) microscopic image of cut mark showing V-shaped appearance of kerf.

Figure 12. Macroscopic image of Cat#433 (left) & 434 (right): articulating lumbar vertebrae showing associated parallel cut marks across two elements.

Cut mark morphology reflects the morphology and composition of the tool's cutting edge (e.g. bifacial or unifacial tool, stone or metal tool, etc.) and the action of the cut (e.g. the angle at which the tool was held, the direction of motion, false starts and stops, etc.). While some of the indicators of this morphology are visible macroscopically, many are best viewed with the SEM.

Stone tool cut marks are best distinguished using the SEM to identify the existence of a U- to V-shaped cross-section and multiple striations on the walls of the kerf that run generally parallel to the long axis of the cut mark (Bueschgen and Case 1996; During and Nilsson 1991; Eickhoff and Herrmann 1985; Hurlbut 2000:7; Lyman 1994; Noe-Nygaard 1989; Shipman 1981b) (Figure 13). Stone tools will produce irregular and wide grooves compared to metal cut marks and will tend to be asymmetrical, reflecting the asymmetry in the stone tool (Greenfield 1999:804).

Striations in cut marks result from imperfections in the tool and dislodged particles being dragged the length of the cut (Shipman 1981b:366).

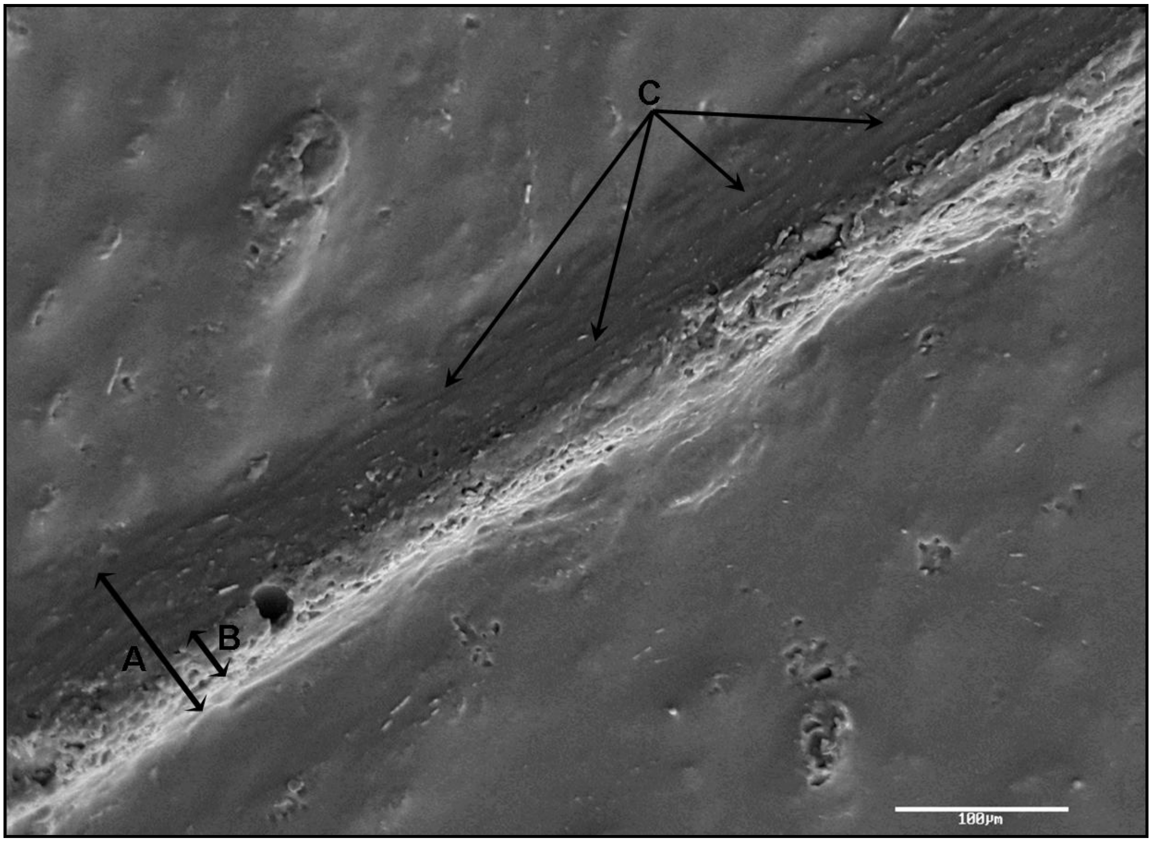

Figure 13. SEM image of Xantopren® mould of stone cut mark from Cat#277 (x200 magnification) showing deep, angled (A-B) cut mark, rounded kerf apex (B) and multiple longitudinal striae (C).

Noe-Nygaard (1989:471) observed that, in addition to longitudinal striae on the walls and bottom of the kerf in stone tool cut marks, the upper edges of the kerf walls may exhibit striae that are perpendicular to the log axis "reflecting the uneven edge of the cutting implement". This characteristic was also recorded by Binford (1981b) and by some SEM investigations (Shipman 1981b; Behrensmeyer et al. 1986).

Nonhuman agents may produce individual cut mark mimics that are indistinguishable from stone tool cut marks, even under magnification (Shipman and Rose 1984; Andrews and Cook 1985; Lyman 1987; Fiorillo 1989; Oliver 1989). However, it has been argued that some of features may be cut mark diagnostics. These include “barbs” and “shoulder effects” identified by Shipman and Rose (1983a:66), and “splitting” identified by Eickhoff and Herrmann (1985). Barbs are small divergences at the head or tail of the cut mark.

Shoulder effects are accessory grooves found outside the main cut mark groove (Figure 11). Shipman and Rose (1983a:66) described shoulder effects as “short marks which accompany slicing marks and which are made with the same stroke as the slicing mark. Shoulder effects may parallel or diverge from the main groove for part of its length.” Shipman and Rose (1983a:66) suggested that shoulder effects are the result of “contact between the tool’s shoulder and the bone during cutting”. However, Oliver (1989:89) asserted that shoulder effects could also be created by trampling. In addition, while these features may be indicative of stone cut marks, they do not appear on all, or even a majority, of cut marks.

Macroscopically, metal cut marks have been described as being deep, with sharply V-shaped cross-sections, with thin islands of bone within and between concentrations of marks (Figure 14), such as those observed by Armour-Chelu and Andrews (1996). Metal cut marks can also appear as fine hairline incisions with thin shelves of bone in angled marks (Binford 1981b:105).

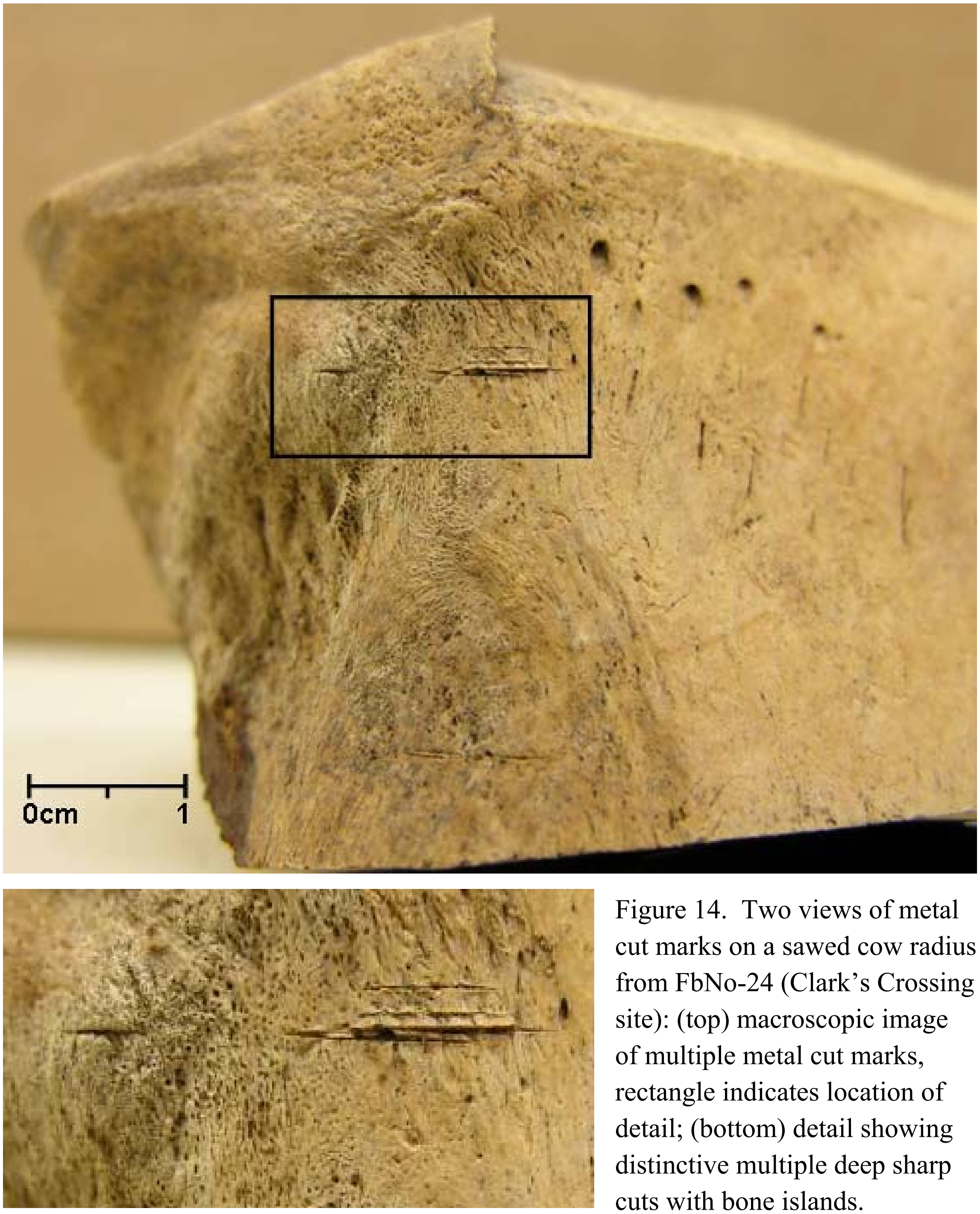

Figure 14. Two views of metal cut marks on a sawed cow radius from FbNo-24 (Clark's Crossing site): (top) macroscopic image of multiple metal cut marks, rectangle indicates location of detail; (bottom) detail showing distinctive multiple deep sharp cuts with bone islands.

In contrast to stone tool cut marks, metal knife cut marks generally do not show internal striae within the kerf and, if they do, striae are very regular or continuous and often few in number, reflecting nicks in the blade. Metal cuts are unlikely to cause shoulder effects or split terminations. While cross-sectional morphology will vary, metal cut marks will tend to be very sharp and steep compared to stone tool cuts. However, Greenfield (1999:804) noted that dull blades may leave a kerf with steep sides and a flat or U-shaped kerf floor and blades with scalloped edges leave marks resembling saw cuts, that are “broad and poorly defined”.

The technique used when applying a tool is also reflected in the cut mark. According to Walker and Long (1977:608), sawing motions with a steel knife will produce a series of parallel grooves representing the multiple strokes but “when they are seen in cross-section they usually deface only one side of the groove”. Flaked tools used with similar motions will produce “an abraded undulating surface characterized by shallow U-shaped grooves that deface a relatively large area of bone on either side of the cut”. Walker and Long (1977) found that modified or bifacial stone tools produce variable marks that tend to be wide and irregular in form due to their undulating cutting edge. They “usually do not terminate in a single apex and they have concave rather than straight sides” or may produce “a series of shallow interconnected grooves” with a single cutting stroke (Walker and Long 1977:608) (Figures B25–B29).

Binford (1981b:169) described cut marks from stone tools as “most commonly made with a sawing motion resulting in short frequently multiple but roughly parallel marks” and also noted that “they rarely follow the contours of the bone on which they appear. That is, the cut does not show equal pressure in depressions and along prominent ridges or across the arc of a cylinder”. Figure 15 reveals cut marks that reflect this statement, as does Figure 14.

The angle at which a tool is applied relative to the bone surface will affect the butcher mark produced so that “when a steel knife or flake tool is held at an acute angle, an asymmetrical ‘V’ is formed, the long side of which corresponds to the angle at which the tool was held” (Walker and Long 1977:609). Figure 15 shows the microscopic appearance of several angled cut marks. When viewed from above using the SEM, this can be identified when the apex of the kerf is clearly to one side with an overhang visible on the side closest to the apex. This is illustrated by Figure 13, which also indicates how to identify the boundaries of the kerf edges in the SEM image.

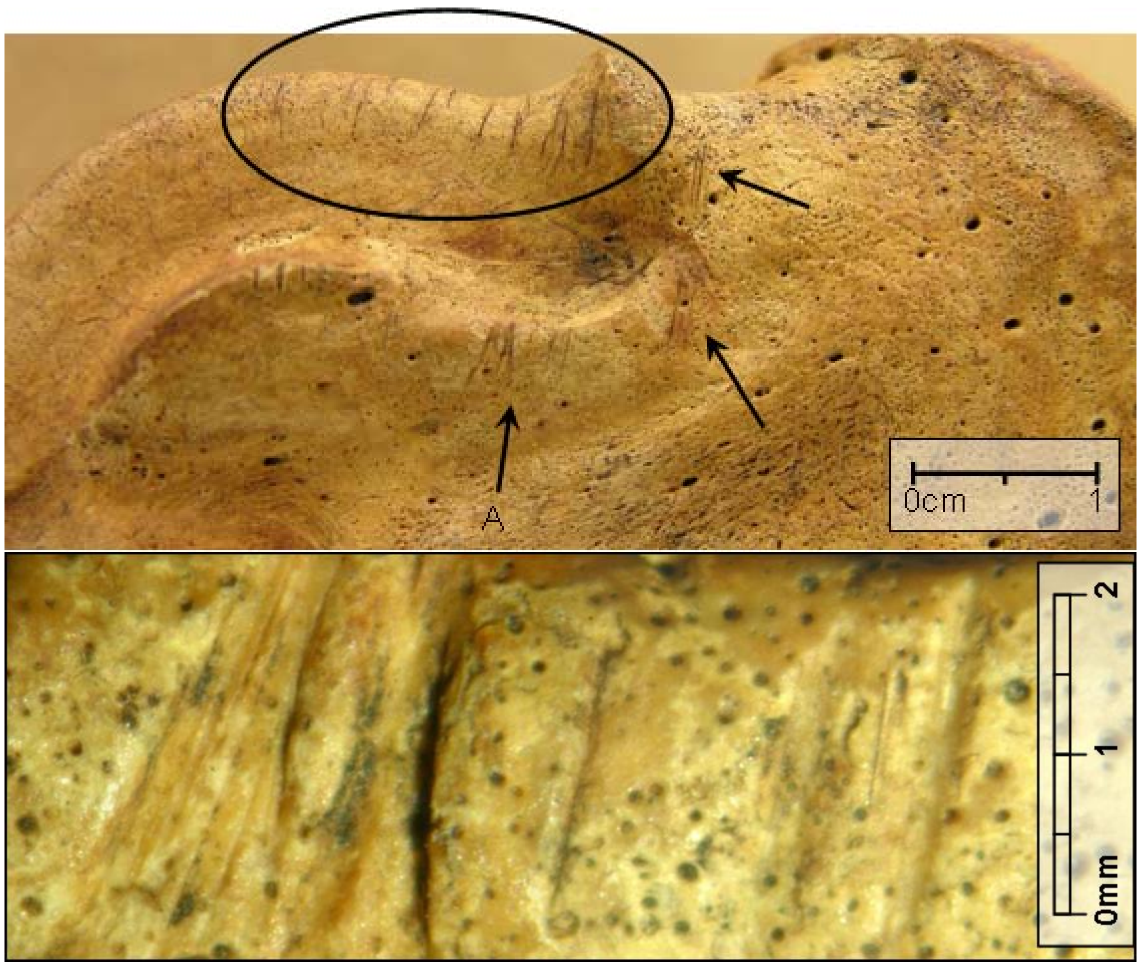

Figure 15. Two views of Cat#634: (top) macroscopic image of astragalus with multiple stone cut marks (arrows) and weathering cracks (oval); (bottom) microscopic image of cut marks at “A” showing angled, overlapping appearance.

Pickering and Hensley-Marschand (2008) stressed that cut mark angle is related to handedness as well. However, the determination of handedness is inextricably linked to the ability to determine directionality of individual cut marks. Some dissent exists as to whether the directionality of cut marks can be reliably identified. Shipman and Rose (1983a), in their investigation of directionality of slicing cut marks focussing on overall cut mark features such as mark width and barb presence, "found no features that consistently and accurately identified either the head or tail end of slicing marks" (Shipman and Rose 1983a:75).

Bromage and Boyde (1984) employed "bone smears", "oblique faulting", and "oblique chipping" as indicators for identifying directionality. In his investigations of forensic knife marks in bone, Houck (1998) also observed directionality from bone smears in metal knife cuts, explaining that "as the blade passes through the bone, it crushes the nascent surface of the cut and produces "lifts" in the opposite direction" Houck (1998:419). However, applications to archaeological cut marks have yet to be fully investigated.

4.3. Pseudo-Tool Mark Morphology

Most general forms of pseudo-tool marks can be distinguished from each other relatively easily using macroscopic information, although specific identifications can be more difficult. However, a trend can be seen in which marks that cannot be reasonably identified macroscopically can be identified microscopically (such as carnivore tooth marks) and vice versa (such as trampling marks). Pseudo-tool marks can result from any number of sources (Table 5). Table 5 outlines the most common sources of pseudo-cut marks. Besides these, there are also less common considerations such as invertebrate actions, digestion, or rock fall.

Table 5. Features of Common Pseudo-Cut Marks

Source	Typical Mark	Location (typically)	Cross-section	Form	Cause(s)
Chewing by carnivores, rodents, large herbivores	Tooth marks	Varies depending on actor	Varies depending on actor	Varies depending on actor	Tooth impact, pressure, or scraping.
Plant actions	Root etching	Any	Rounded	Varies	Root acids dissolve bone
Modern human action	Trauma	Any	Large or fine	Irregular edges, lighter colour than surrounding bone, no or patchy matrix in groove	Archaeological trauma (field, lab, curation or testing procedures) or other damage (e.g. Agricultural)
Particle abrasion and trampling	Scrapes	Any, often a large % of bone surface if present	Fine but variable	Multiple fine linear grooves	Trampling by animals or humans, environmental or mechanical disturbance such as rock fall
Weathering and surface erosion	Weathering Cracks	Any, usually parallel to the long axis of the bone	Varies depending on depth and width of crack	Irregular, ending in points	Exposure, wet/dry or freeze/thaw cycles, desiccation
Natural bone morphology	Vascular impressions	Any	Varies	Channels for blood vessels; often associated with a foramen	Natural growth of the bone associated with soft tissue or bone formation

Note: refer to text for specific references

Alteration by living organisms is an important source of pseudo-cut marks that will be discussed in five major groups: carnivore damage, rodent damage, large herbivore damage, invertebrate damage, and plant damage. While some of these mark types may be on a similar width scale with cut marks, they will tend to be otherwise macroscopically and microscopically dissimilar in morphology.

Blumenschine et al. (2007:422) explained that many cases of plant and animal damage would be quite fine (typically, 10 to 100 μm wide and 0.5 to 2mm long) although larger mark types like carnivore damage are generally at least 1mm wide. Cut mark widths tend to be quite variable. The majority of cut marks observed in the Blumenschine et al. (2007) study were on the scale of 100μm wide, whereas Walker and Long (1977) observed that typical widths for steel knife and obsidian flakes cut marks to be up to 1mm wide, stone biface cut marks to be up to but not exceeding 4mm wide.

Bunn (1981:575) observed that "at FLK Zinj, mean width of 382 cut marks is 0.23 mm, and mean width of 146 carnivore gnaw marks is 0.70 mm. Typical carnivore gnaw mark is thus 3-4 times wider than a cut mark". However, Shipman (1983) and Shipman and Rose (1983a:63) suggested that width, much like cross-sectional morphology, is an unreliable criterion to distinguish between carnivore tooth marks and cut marks, although it can be applicable to more general uses.

As previously discussed, the issue of animal chewing of bones, particularly carnivore gnawing, has been the subject of much paleontological, palaeoanthropological, archaeological, and forensic research. Shipman and Rose (1983a:81) (also Potts and Shipman 1981; Shipman 1981a, 1981b) emphasized three gnawing mark types of importance: "tooth scratches, incisal gnawing marks, and punctures". They also recognized furrowing of articular ends as evidence of carnivore gnawing that should not be mistaken for tool marks. Similarly, Binford (1981b:44) suggested that carnivores will produce four general mark forms on bone including punctures, pits, scores, and furrow marks (Table 6).

Table 6. Features of Common Tooth Marks

Mark type	Location (typically)	Cross-section	Form	Cause(s)
Punctures	Thinner bone (e.g. Epiphyses, scapula blade)	Bone fragments crushed inwards	Circular or oval	Impact or pressure of tooth on bone, perpendicular to surface. May show opposing marks on multiple surfaces.
Pits	Dense, hard bone (e.g. Long bone shafts); may also appear in thin bone if insufficient pressure applied	Cone shaped impressions, no bone fragments		
Scores	Long bones	V- or U-shaped, smooth groove	Long grooves	Pointed cusp of tooth (usually canine) drawn across bone. May show opposing marks on multiple surfaces.
Furrows	Cancellous bone	Variable	Concentrations of damage, graduated against compact bone; bones may have scooped out appearance	Canine or carnassial tooth action; most common animal related tooth damage
Rodent gnawing marks	Fractures; edges of thin areas (e.g. Ribs)	Broad, shallow, flat bottomed, possibly parallel striae	Two or more parallel grooves, may cause "windows" in bone; may exhibit chattermarks	Incisors drawn across bone
Herbivore chewing	Any	Varies	Characteristic "forking", sometimes undulating damage	Cheek teeth working against each other

Note: refer to text for specific references

Punctures occur where the bone has collapsed under the impact of a tooth, usually the canine (Figure 16). As in tool-made impact marks, small bone fragments may be present in the groove of a puncture mark, but punctures tend to be circular or oval depending on the form of the tooth as opposed to the elongate ovals or grooves of chopping marks (Shipman 1981b:366). Pitting is similar in origin to puncture marks but occurs when a bite is delivered with insufficient force to cause a puncture; this usually occurs at locations of harder bone (e.g. diaphyses as opposed to epiphyses).

Figure 16. Two views of Cat#843: (top) macroscopic image of carnivore tooth punctures and pits on scapula blade with black rectangle indicating location of detail; (bottom) detail with white oval highlighting punctures and pits and arrow indicating natural bone feature with foramen on the left side.

Scoring marks are produced by dragging the teeth across the bone or through rotating a bone beneath the teeth using the forepaws (Binford 1981b). Small single or parallel scoring marks can resemble slicing cut marks. Morphologically, score marks in cortical bone are usually of uniform depth below the bone surface, following the contour of the bone (Binford 1981b:46-47). This is in contrast to stone tool cut marks, which tend to be straight cuts through bone that are deeper where the bone curves.

Shipman (1981b:366) pointed out that the fine striations that occur in stone tool cut marks are notably absent from the microscopic structure of any of her observed carnivore tooth marks. Shipman (1981b) attributed the absence of striations in tooth marks to an evolutionary selection for smoother enamel to reduce tooth damage. However, Eickhoff and Herrmann (1985:272) asserted that fine striae were observable in carnivore tooth marks from their collection (discussed above), possibly resulting from "ragged" carnassial teeth. Schrenk and Maguire (1988:293) also disagreed with Shipman (1988:267) on this point when they found some score marks (which they called "striations") made by hyenas on chewed bone to show "fine substriations within and parallel to the groove". Shipman (1988) suggested that the potential existence of sub-striations might be due to overlap of score marks in a similar manner to concentrations rodent gnaw marks (described below).

While tooth marks rarely show any fine striae, chatter marks may occasionally appear within the groove. Shipman and Rose (1983a) observed that chatter marks may appear in both carnivore and rodent gnaw marks and described them as "small ridges perpendicular to the long axis of the groove produced by variations in the resistance of the bone surface to gnawing" (Shipman and Rose 1983a:84).

Landt (2007) utilized the SEM to investigate human tooth marks on small mammal bones. Landt (2007) described these marks as appearing circular to elongate oval or sometimes relatively irregular in shape and ranging in size with large pitting marks averaging 5mm in width. Similarly, Laroulandie's (2002:27) study of macroscopic anthropogenic damage morphology on bird bones identifies circular to oval compressions of 1 to 5mm in length as human tooth marks. Landt (2007:1638) suggested that human mastication of bones morphologically resembles that of other carnivores but differs in its pattern.

Pickering and Wallis (1997) utilized the SEM in their experiments regarding experimental chimpanzee tooth marks. Chimpanzee bone gnawing was found to be from carnivore gnawing based on microscopic criteria, making a more configurational approach necessary (Pickering and Wallis 1997:1124). They (Pickering and Wallis 1997:1124) contradicted the findings of several other researchers (e.g. Hill 1980, 1989; Johnson 1989; Bunn 1989) by arguing that tooth mark morphology does not reflect the characteristics of a particular actor but is the result of properties of the bone itself.

Several differing views exist as to the correct criteria to consider when identifying carnivore tooth marks. Blumenschine and Marean (1993:273) suggested that carnivore marks tend to have crushing evidence within the groove regardless of mark type (pit, puncture, or score). Oliver (1994:272) argued that marks resembling carnivore tooth marks should only be considered as indicative of carnivore action if both pits and scores occur in an area in significant concentrations and/or are associated with other diagnostic features of carnivore action. Oliver (1994:271) stressed that carnivore marks should be considered a "suite of characteristics" rather than being individually diagnostic.

Morlan (1984:162) summarized the general attributes that can be used to distinguish between cut marks and tooth marks including: "(1) the anatomical element that is marked; (2) the position of the element; (3) the gross morphology of the mark; (4) microscopic features within the mark; (5) comparison between the contour of the mark and that of the bone surface". Conversely, Eickhoff and Herrmann (1985) noted six important categories of attributes that may be applied as supporting evidence for the presence of carnivore gnawing. These include location, width, cross-sectional shape, lesions of a circular type, terminal damage phenomena, and differential damage (Eickhoff and Herrmann 1985:264). Horton and Wright (1981:74) used "the opposition of marks" and "form and origin of the cut marks" (including length, depth, and cross-sectional morphology) as key indicators of carnivore vs. tool marks.

Tooth marks can be found both in concentrated in areas of high gnawing activity or as isolated damage. Shipman and Rose (1983a:86) noted the potential for butchering an animal to produce no cut marks at all whereas "relatively more bones from carnivore-chewed or rodent-gnawed assemblages will show toothmarks, because these animals chew the same area repeatedly" (Shipman and Rose 1983a:88). In her experiments concerning the appearance of hominid scavenging, Selvaggio (1994) examined carnivore dismembered carcasses that were subsequently experimentally butchered using stone tools. She found that appearances of carnivore marks were more common than cut marks and both were most often apparent on epiphyseal ends (Selvaggio 1994:223).

Carnivores preferentially attack specific locations such as the articular ends of long bones (Binford 1981b:76); such locations have relatively thin layers of cortical bone and high returns in terms of marrow yield. Rodents will be more likely to chew at thin edges of bone such as ribs, sections of the mandible, or fractured areas. Binford (1981b:49) also notes the potential for the "production of 'windows' in the shafts of bones which are a diagnostic of rodent modification".

Rodent gnawing patterns will vary based on the specific bone products being sought by each species. In their rodent gnawing experiments, Klippel and Synstelien (2007:771-772) found that rats will gnaw at different locations of the bone than will grey squirrels. Rats are usually pursuing flesh and nutrients (such as fats and grease) while gray squirrels, being herbivores in search of mineral supplements, attack bones once these products are completely removed. The result is different gnawing patterns for different rodents. Like large carnivores, rats will prefer areas of thin cortical bone, whereas squirrels prefer thick cortical bone at narrow locations.

Rodent gnawing marks result from dragging the incisors across the bone towards the animal in a manner that is functionally similar to scraping marks. Rodents will tend to leave small parallel marks on bone corresponding to the incisors, though rodent modification of bones can be much more extensive in localized areas. Shipman and Rose (1983a:82-83) recognized two patterns of rodent gnawing called "fan-shaped" and "chaotic". In the fan-shaped form, the upper incisors stay at a stationary point on the bone with the lower incisors moving across the bone (more typical of squirrel-chewed bone) (Shipman and Rose 1983a:82-83). In the chaotic form, "both upper and lower incisors are drawn across the bone towards each other, so there is no set pivot point" (Shipman and Rose 1983a:82-83). This is more typical of animals such as mice and porcupines. Chaotic rodent gnawing often occurs in long regular rows at narrow bone edges (Figure 17), but sometimes occurs in irregular patches.

Shipman and Rose (1983a:82) described rodent gnaw marks as “broad, flat-bottomed grooves often occurring as a series of parallel or subparallel marks”. They note that such marks may mimic scraping marks in their form because “fine parallel striations running longitudinally in these grooves can be observed in some specimens; these are infrequently present and result from repeated gnawing in a small area” (Shipman and Rose 1983a:82). The troughs of repeated gnaw marks will overlap imperfectly, causing small ridges between mark apexes.

Figure 17. View of Cat#213: macroscopic image of coronoid process and mandibular notch showing chaotic rodent gnawing.

Both modern and fossil porcupine-accumulated bone assemblages tend to have high percentages of specimens exhibiting distinctive porcupine gnaw marks (Brain 1981:109-117; Maguire et al. 1980). Schrenk and Maguire (1988:293) described porcupine-gnawing marks as “broad, contiguous, and shallow scrape marks...up to 5mm wide and characterized by V-shaped sub-grooves between superficially rounded ridges”. Shipman and Rose (1983a:84-85) explained this as originating from repeated gnaw marks forming a single trough.

Tooth marks from large herbivores result from the chewing action of the upper and lower molars and premolars. Multiple instances of bone chewing by deer in which the bone was held in the cheek teeth in a “cigar-like” manner have been observed (Sutcliffe 1973:428). Kierdorf (1994) explained osteophagia in ungulates as resulting in a characteristic forked appearance to the remaining bone. Sutcliffe (1973) described several examples of this phenomenon including occurrences of an idiosyncratic zigzag appearance that will sometimes occur. Warrick and Krausman (1986) suggested that this behaviour might supplement phosphorous deficiencies in the diet of big horn sheep, as opposed to a need for calcium or other trace minerals. This is in accordance with Sutcliffe’s (1973:430) research in which he cited known examples of bone chewing by deer in calcium rich areas.

Stomach acids acting on bone can erode or dissolve the bone surface or produce damage morphologies such as scalloping, smoothing, polishing, thinning, or perforation (Cook 1986:151-153). Digested bones will typically exhibit a combination of these features and should be readily identifiable in uncompromised bone (Fisher 1995:42). Small mammal bones are more commonly the recipients of digestion (e.g. Fernández-Jalvo and Andrews 1992), although large mammal bone fragments are sometimes recovered from carnivore digested remains (e.g. Hill 1989). Rensberger and Krentz (1988:1543) explained that digestion reveals itself as fine fissures in the bone surface ranging from “thin, cracklike [sic] fissures” to “slightly compressed oval openings”, of variable size but generally visible at magnifications of x100 or greater. These features are much too fine to be mistaken for cut marks, but it is possible that digestion could mask or deform surface features of true cut marks.

The actions of invertebrates are also known to cause bone alterations. Insects such as beetles, moth larvae (Behrensmeyer 1978), or termites (Watson and Abbey 1986; Behrensmeyer 1978) have been known to damage bone, leaving round bore holes, worm tracks, or other trace (Shipman 1981a:111). Pupation chambers excavated by arthropods in bone leave the bone with a pitted appearance (Gautier 1993:Figure 2). These can be much the same in form as similar alterations by insects to wood and similar plant matter. Schultz (1997:210) noted that "traces of damage caused by small insects are only judged correctly in a few cases, since they are similar to traces of damage from roots and not easily recognized". Fernández-Jalvo and Monfort (2008) observed that bone surface damage caused by dermestid beetles in museum settings can include irregular edged holes, grooves, and bite marks. These features are very fine and often visible only microscopically and should not be mistaken for alterations caused by larger species.

Modifications associated with plant activity and growth has been a source of some confusion in interpreting the archaeological record. Plant damage can include actions of lichens and mosses. Cook (1986:157) stated that "lichens have been observed to produce pitted, rosette-like marks" on bones during periods of surface exposure. Andrews and Cook (1985:687) observed that moss growing on bone can produce a "dendritic pattern of stained lines" on the bone surface. However, as previously mentioned, the process of root etching in particular can result in confusion regarding mark identification.

Root etching occurs when a bone is dissolved by the acids associated with roots that encounter the bone surface. This results in marks with an undulating, meandering form and a semi-circular or U-shaped cross-section mirroring the curvature of the root

(Figure 18). These marks can result in elaborate patterns that have been misconstrued as decoratively engraved bone artifacts (Binford 1981b:49). Root etchings are macroscopically and microscopically dissimilar to butchering marks and in general should not be mistaken for cut marks. However, extensive root etching will aid in the degradation and erosion or flaking of the bone surface, which can interfere in cut mark analysis.

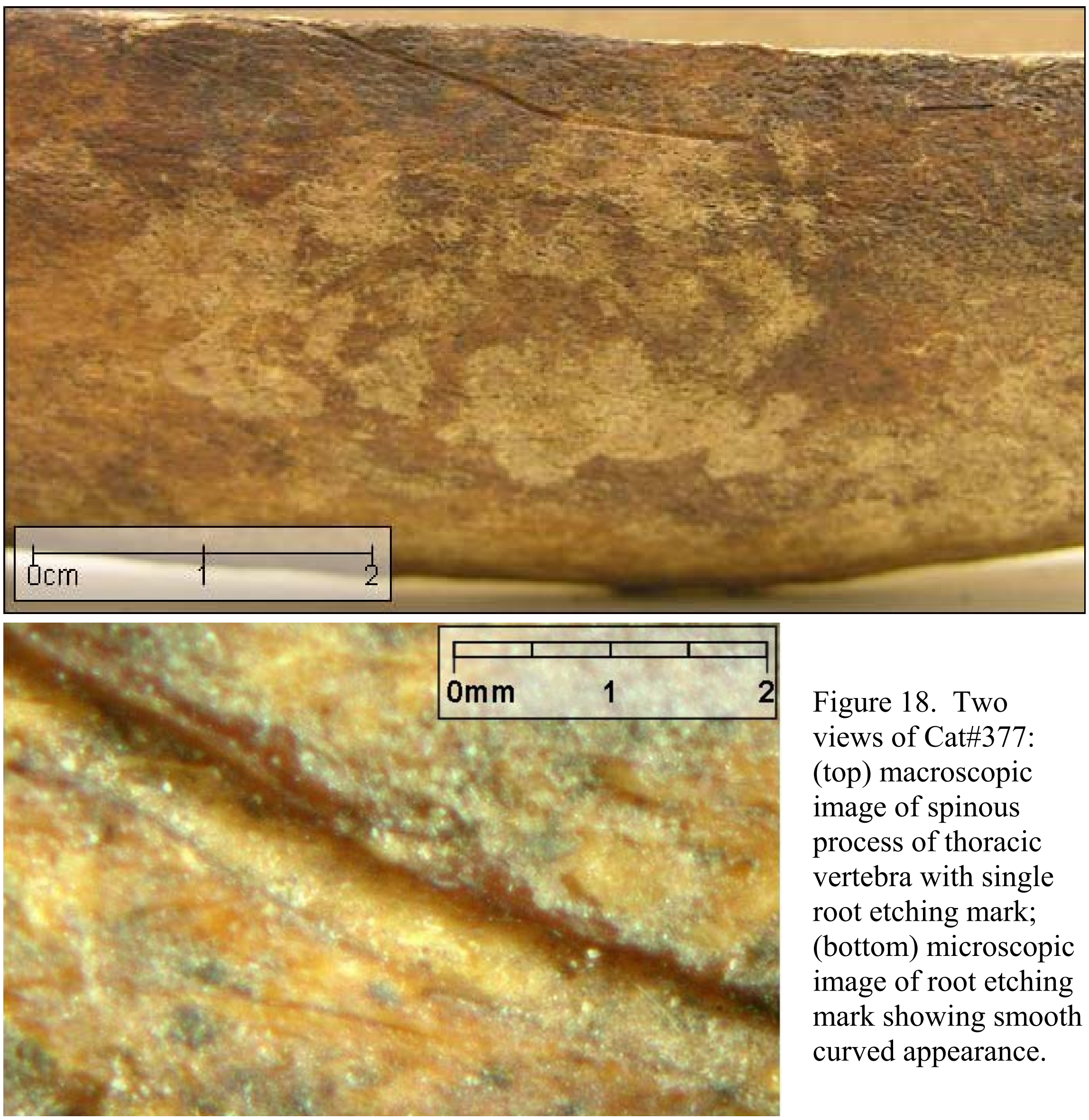

Figure 18. Two views of Cat#377: (top) macroscopic image of spinous process of thoracic vertebra with single root etching mark; (bottom) microscopic image of root etching mark showing smooth curved appearance.

Root etchings can also be mistaken for another pseudo-cut mark category, that of antemortem skeletal alterations such as natural bone features like blood vessel impressions (Schultz 1997:206). Identification is made more difficult by the fact that root growth will sometimes follow the paths of natural bone features along the bone surface and into or through natural foramina. Vascular grooves are variable in their morphology, although there due tend to be regularities in location (Morlan 1984). Like root etching, vascular grooves will sometimes appear to meander across the bone, following the bone surface. The cross-section is variable, ranging from "open, shallow U-shapes to nearly closed, deep circles" (Morlan 1984:164) to shallow depressions (Figure 19). Often, grooves for blood vessels will be associated with foramina in the bone (Figure 16).

Fisher (1995) notes that "[m]ultiple, closely spaced, parallel vascular grooves that can be imparted by a set of bifurcated arteries or accompanying nerves may have the appearance, macroscopically, of a cutmark with internal striations" (Fisher 1995:46). Shipman and Rose (1984) explain that "unlike that of cutmarks, the groove surface in these marks is unusually smooth under SEM inspection, has some but few ridges, and contains many small openings or pores" (Shipman and Rose 1984:117). This morphology is evident when the marks in Figure 19 are examined using the SEM.

Extensive weathering (like root etching) may result in distortion of the bone surface, which makes distinguishing cultural marks difficult and sometimes the extent of the damage may make it impossible. Weathering processes such as abrasion by wind-blown sand, freeze-thaw action, water transport, erosion, or post-depositional movements or other similar depositional processes leave cracks in the bone surface that may imitate or interfere with true cut marks (Figure 15). Weathering can cause splintering, exfoliation, or polishing of the bone surface. Weathering damage may also leave deceptive discolouration on the bone, however this can be dismissed because there will be no associated groove.

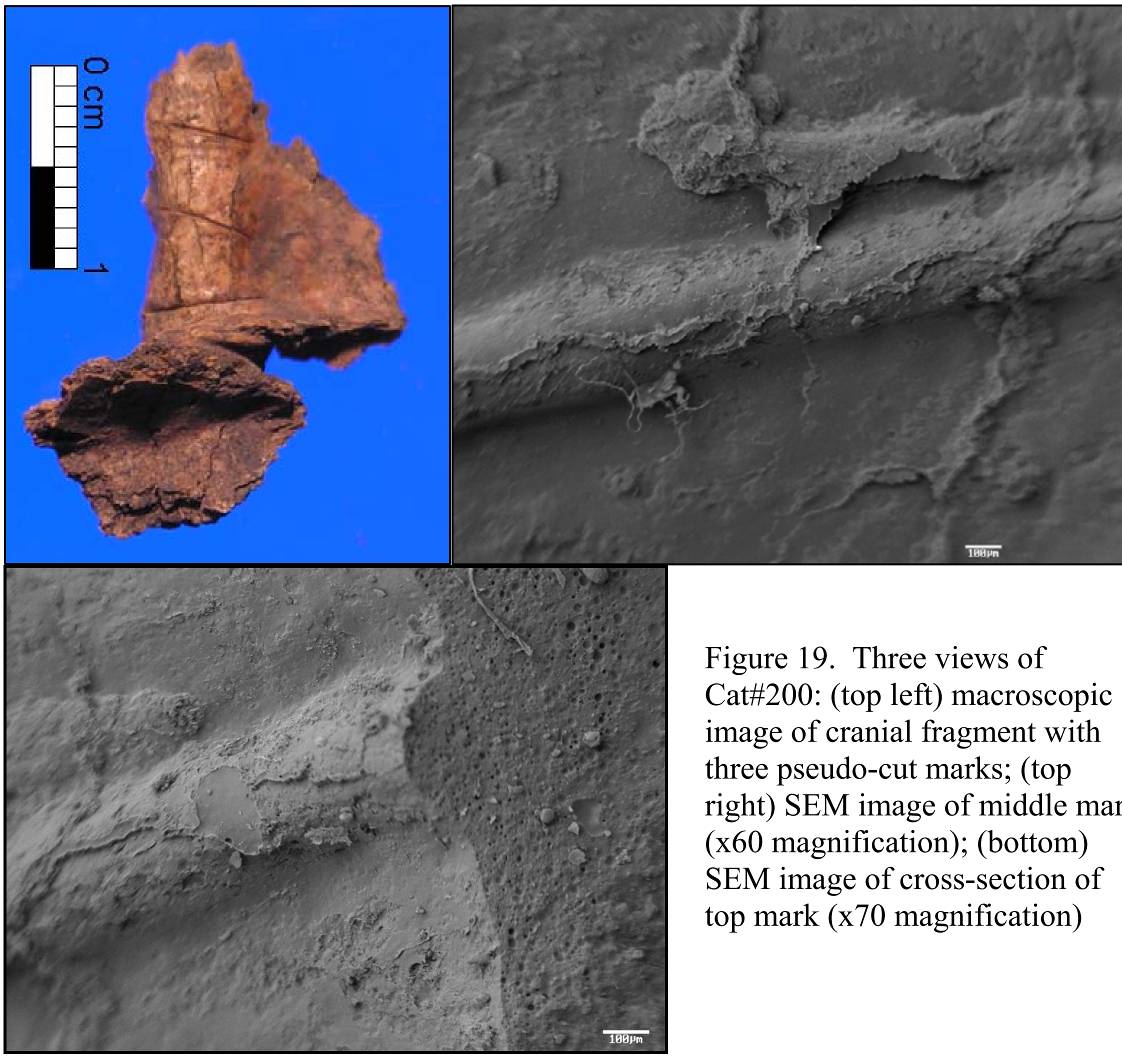

Figure 19. Three views of Cat#200: (top left) macroscopic image of cranial fragment with three pseudo-cut marks; (top right) SEM image of middle mark (x60 magnification); (bottom) SEM image of cross-section of top mark (x70 magnification)

Split-line cracks are weathering cracks that follow the long axis of bones (Tappen 1969) (Figures 15 and 20). Such cracks are generally caused by desiccation of the bone or temperature changes. This can result from natural weathering processes such as wet-dry or freeze-thaw action (Bonnichsen and Will 1990:9) or immersion in heated water (Fernández-Jalvo and Monfort 2008). Similar processes can also result in exfoliation of bone and internal splitting that follows the bone surface (Figure 7), which causes it to exhibit onion-like layering (Bonnichsen and Will 1990:9). This is in contrast to split-line cracks, which have a depth that is perpendicular to the bone surface. Split line cracks tend to follow a meandering path, have a jagged appearance, and irregular tapering ends and cross-section (Figure 20).

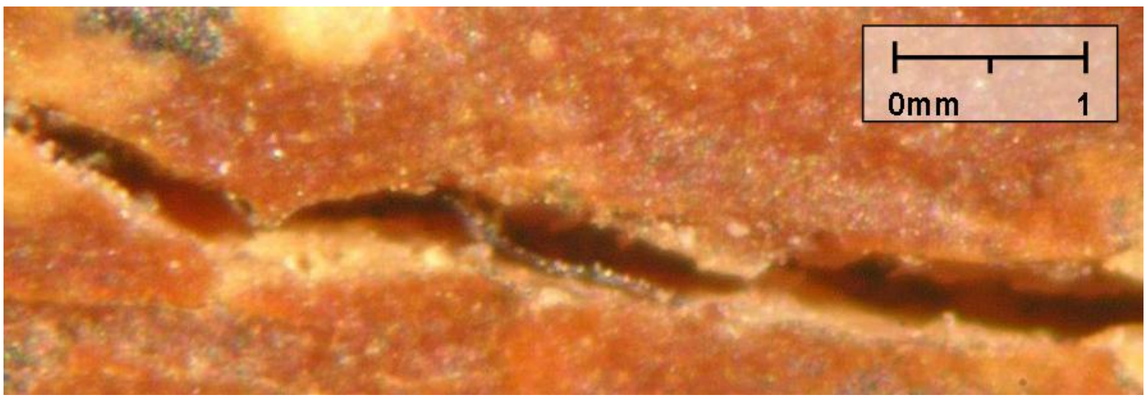

Figure 20. Microscopic image of Cat#516 weathering crack showing meandering appearance, jagged edges, and irregular apex.

Sedimentary abrasion is another key general source of pseudo-cut marks. This is a cause for controversy because it has the same causal component and can arguably mimic the microscopic morphology of cut marks very closely. Large complexes of scratches on bone arising from particle abrasion (such as from processes like trampling or depositional abrasion, etc.) should not be mistaken for cut marks simply because the microscopic morphology of some of the individual marks will mimic stone tool cut marks. Behrensmeyer et al. (1986) suggested that microscopic features alone are not sufficient to distinguish trampling from tool marks and therefore other lines of evidence and contextual information must be considered. As previously described, it is desirable that multiple factors be considered first to provide as much information about the mark and its context as possible before costly and time-consuming microscope work is undertaken. In this scenario, it is important to consider macroscopic and contextual information in identifying probable agents.

Particle abrasion can result from several different scenarios including wind, water transport, mechanical transport, post-depositional soil movements, or trampling. Behrensmeyer et al. 1989:116) noted that "sand-blasting" and water transport is more likely to cause polish or exfoliation to the bone surface than surface scratches that could be construed as pseudo-cut marks. Shipman and Rose (1983a:79) suggested that sedimentary abrasion is more likely to obliterate cut mark features than produce them, and found no abrasion marks that exhibited fine parallel striae within the groove. Behrensmeyer et al. (1989:116-117) also suggested the possibility that "depositional scratching" or post-burial soil movements of "[n]onhomogeneous fine-grained sediments containing angular sand could cause randomly distributed scratches over the bone surface, and this could be an important cause of both single scratches and clusters of parallel scratches".

Many studies have recognized the potential for the combination of sandy or rocky substrates and pressure from large mammal hooves to produce trampling marks (e.g. Behrensmeyer et al. 1989; Andrews and Cook 1985; Haynes and Stanford 1984; Oliver 1989, 1993; Olsen and Shipman 1988). This is in contrast to trampling in finer grained substrates, which is more likely to cause polish (Behrensmeyer et al. 1989:115). Fiorillo (1989:66) observed that, while the morphology of trampling marks can vary significantly, some "scratch marks have a strong V-shaped cross-section and are similar to cut marks". However, there is also a tendency for trampling marks to appear as "sets of shallow, subparallel scratches" (Fiorillo 1989:66), which can appear as U-shaped to V-shaped, linear to curvilinear, and can show "numerous subsets of very shallow scratches" along with deeper scratches or "show smaller grooves running longitudinally within the large deep grooves" (Fiorillo 1989:Figure 9).

Microscopically, trampling marks tend towards a very fine and shallow morphology and an association with surface polish in highly trampled assemblages (Olsen and Shipman 1988:550-551). Fiorillo (1989:66) asserted that trampling marks exhibit very similar micromorphology to cut-marks even when utilizing the SEM. Oliver (1989:89) observed that trampling marks could sometimes exhibit shoulder effects resembling those found in many cut marks. However, while individual marks can be indistinguishable from cut marks in many ways, other aspects of their location, orientation, and frequency are not.

While abrasive particles from trampling actions can leave faint, shallow grooves on bones similar to slicing cut marks, the most commonly mimicked type of mark is a scraping mark because of the incidence of multiple linear grooves. As Fiorillo (1989:67) explained, trampling marks tend to appear as sets of "shallow, subparallel scratches". These can be present on any bone at any location and tend to occur in high concentrations compared to true cut marks, both on the bone itself as well as within the assemblage.

Olsen and Shipman (1988:550-551) observed that trampling marks tend to have a higher frequency, both per bone and within the assemblage, than cut marks, as well as a lack of preferred placement, orientation, or implied intentionality. Domínguez-Rodrigo and Yravedra (2009:885) found that frequencies of cut marked bones in archaeological assemblages "can range from <1% to >30%". While this range of potential frequencies is wide, it is in contrast to trampled assemblages that have should as much as 100% of the bones exhibit marks. Shipman (1988:266) notes that most cut marked cases show between one and six cut marks on a single butchered bone. Conversely, Andrews and Cook (1985:681) reported 510 marks on 11 bones from their experimental trampling marks study.

As previously mentioned, Shipman and Rose (1983a) suggested the possibility that the periosteum may protect the bone surface from being marked by tools during butchering. Further to this reasoning, Behrensmeyer et al. (1989:115-116) proposed that "[p]rocesses such as trampling that affect bones after decay of the periosteum might be more effective in scratching bone surfaces than tools on fresh bones". It is a reasonable precaution to treat any specimen exhibiting a large number of marks, especially shallow, subparallel marks, with suspicion. Shipman (1988:266) has even advised that "no analyst should feel comfortable attempting to identify cut marks on a heavily marked assemblage".

The incongruous category of modern cultural alterations or recent trauma to bone associated with human action can include damage done by any number of human activities and machinery that may disturb an archaeological site. In shallow sites, agricultural damage is quite common as is damage due to bulldozers and other heavy equipment used in development. The category of "trowel trauma" is liberally applied to trauma inflicted by archaeologists during excavation.

Unfortunately, because of human error, the fragility of archaeological materials, and unknown nature of sites, no archaeological excavation can be carried out without some resulting trauma. Trauma related to the practice of archaeology can also take place in the lab during cleaning activities, cataloguing, or storage and is sometimes is intentional when it is necessary for testing or experimentation. For example, Behrensmeyer et al. (1986:Figures 2 and 3) illustrated that experimental cut marks can be altered by cleaning trauma.

Modern trauma marks can often be distinguished by examining the colour of the mark (Figures 21–22). It will be lighter coloured than the rest of the bone and may be free of dirt or ingrained matrix (Cook 1986:157; Shipman 1981b:366). Fisher (1995:46) notes that this is not always the case as very shallow striations or crushing may not expose lighter coloured bone. Blunt trauma, inward compression, or polish can even result in a darker colour appearance (Figure 22). Sharp trauma will leave cuts in the bone that are often jagged and of irregular shape, size, and location (Figure 21). Shipman (1981b:366) noted that sharp "preparators' marks" can be very fine but will have irregular, scalloped edges. Modern trauma will be superimposed over older marks (Cook 1986:157) and cross cut surface features and natural weathering.

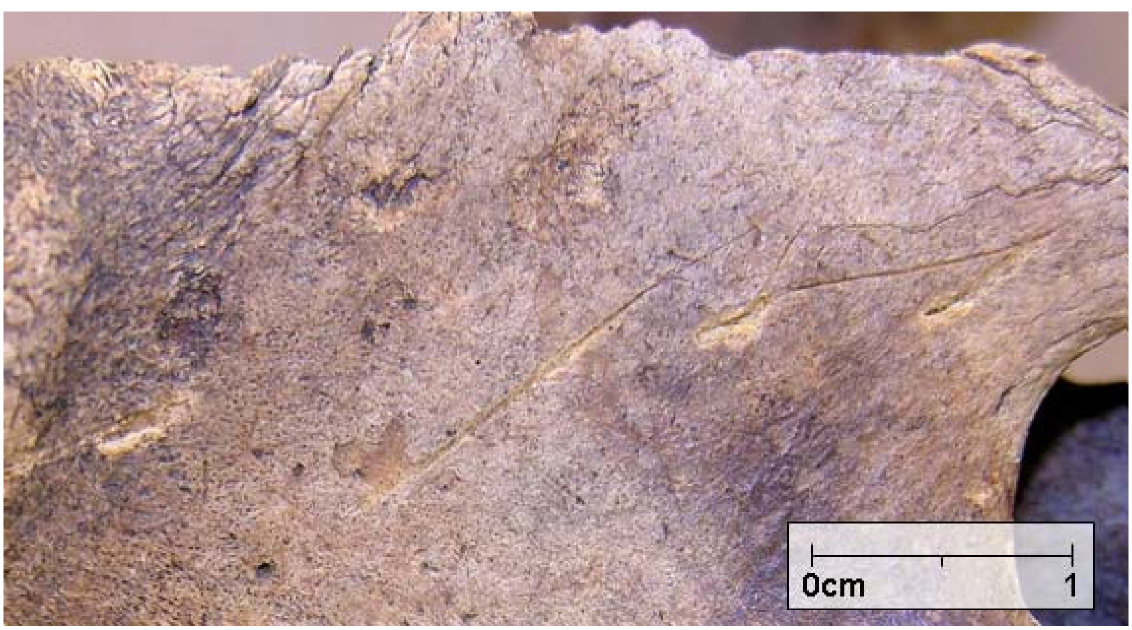

Figure 21. Macroscopic image of sharp trowel trauma on Cat#249 showing lack of ingrained matrix in the grooves and lighter colour than the surrounding bone surface.

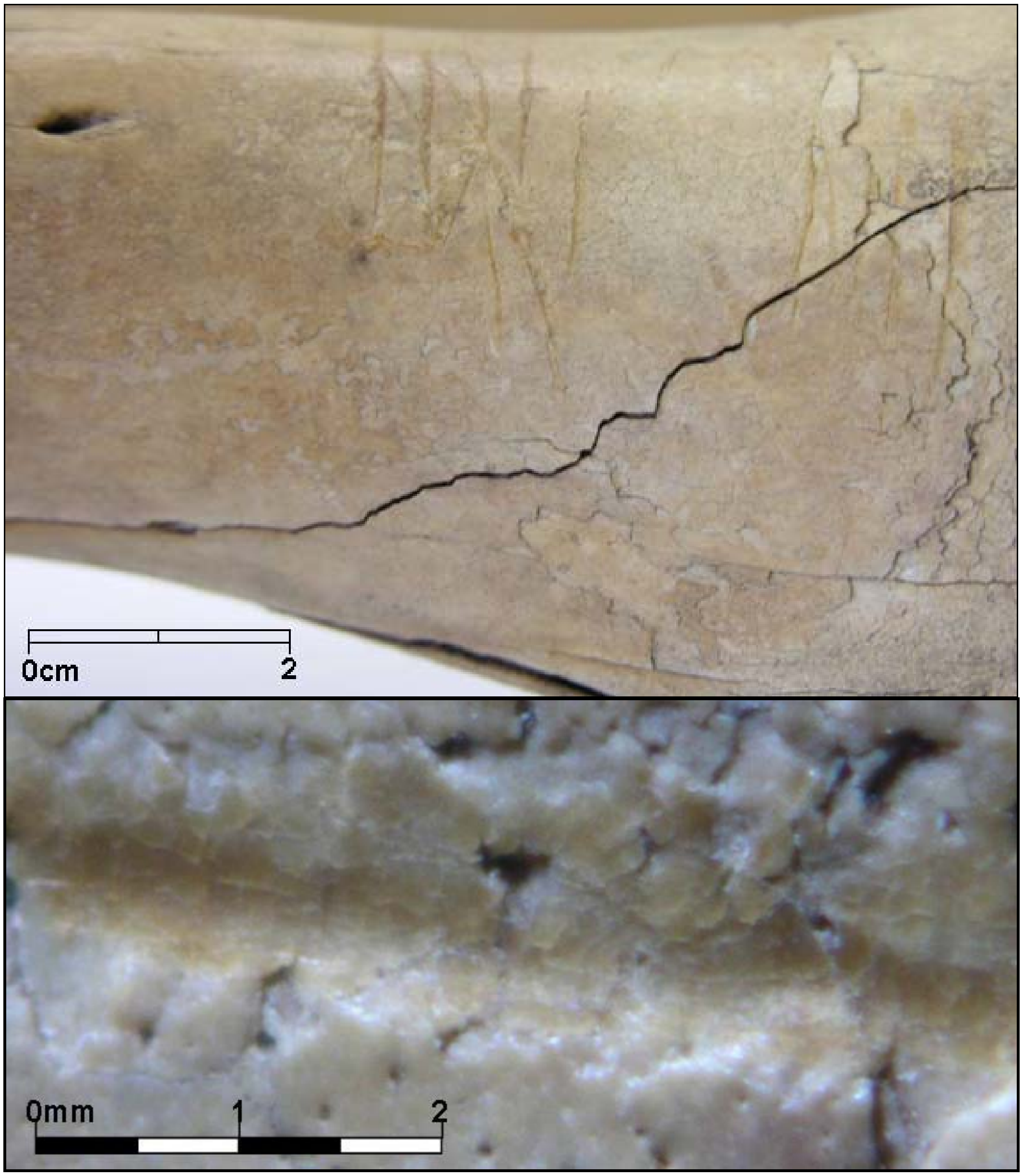

Figure 22. Two views of Cat#510: (top) macroscopic image of humerus showing blunt trauma with polish; (bottom) microscopic image of trauma mark showing polished, compacted appearance.

4.4. Cut Mark Distribution and Frequency

Once a cut mark has been identified to the fullest extent possible, the information can be utilized, within context, to help identify the activity or activities that were associated with its production and the production of the other cut marks in the assemblage. As previously mentioned in sections 3.2.1 and 3.2.3, cut marks have been used to infer butchering patterns, cannibalism, violence, and mortuary patterns. However, while individual marks may be interpreted as to their origin, the identification of an activity pattern, such as a butchery pattern, requires an assemblage of cut marks and is fraught with difficulty.

Lyman (2005:1723) explained the rationale behind the idea of the "butchering pattern". He suggested that, all significant variables being equal (e.g. same taxon, technology, temporal and cultural context), two faunal assemblages should resemble each other in terms of cut marked bone frequencies. Cruz-Uribe and Klein (1994:42) suggested that the "large number of potential variables probably explains why cut-mark [sic] studies such as those summarized by Lyman (1987, 1992) have produced few generalizations".

Variation in butchering pattern is based on both stylistic and functional variables (Lyman 1995:234). Purely functional variables might include the technology available (both in terms of butchering and in terms of processing, cooking, and storage) and the quality, type, form, and material of the tools used (Cruz-Uribe and Klein 1994:42; Lyman 1995:234). The distance from a final destination, scale of the kill, and the number and condition of the hunters will influence degree of carcass segmentation and processing. In addition, variables dependant on the species and condition of the animal will dictate both stylistic and functional considerations (age, sex, and meat and hide quality, cultural dictates regarding different species or types of kills, etc.). The nature of the potentially desired products from the animal will be partially dictated by cultural, economic, and seasonal factors as well. All of these factors can relate both to inter- and intra-group variation of butchering patterns.

Archaeologically, the butchering stage represented by the site, the site type, and degree of processing will correspond to snapshots of steps in a butchering process with differing but interconnected concerns. The type of site being investigated (e.g. kill site vs. camp site) will have significance as to the specific activities being performed, the degree of processing, and what elements will be discarded.

Domínguez-Rodrigo et al. (2007:29) explained that a cut mark analysis must include data on both frequency and distribution to be complete. However, cut mark presence/absence and frequency has proven to be somewhat problematic. Domínguez-Rodrigo and Yravedra (2009:885) have highlighted some of the current conflicts and caution against reliance on total cut mark frequencies. Shipman and Rose (1983a) emphasized that idiosyncrasies of the butchering process and taphonomic variables will affect the production and preservation of cut marks. Even if all cut marks that were produced are preserved, the potential for discrepancies still exists because there will still be a myriad of taphonomic processes that can act to destroy, damage, or mask the cut mark.

Guilday et al.(1962:64) stated that it is possible to butcher an animal without leaving cut marks, and suggested that variance in cut mark presence and frequencies does not mean that a different butchering process was used. Shipman and Rose (1983a:70) argued that periosteum must protect bone from cut marks to some degree. This argument was based on their (Shipman and Rose 1983a:70) experiments which showed that cut marks on bone with periosteum intact are significantly wider than cut marks on bone with the periosteum removed. Egeland (2003) has even suggested that there is no clear correlation between number of arm strokes and number of cut marks produced by a butcher.

Lyman (1987:262) stated that "marks on bones may or may not result from butchering activities because many of these marks are an incidental, not purposeful result of the extraction of carcass resources". Gibert and Jimenez (1991:124) agreed suggesting "the scoring of bone was no doubt a secondary and unpremeditated consequence of obtaining meat, sinews and skin". More recently, Lyman (2005:1723) has reiterated that the occurrence of cut marks is fortuitous and an unintended by-product of butchering activities.

Arguably, this is not to say that cut marks on bone are consciously avoided, simply occasionally inflicted on the bone during butchering when the effort to avoid doing so is unnecessary. However, the presence of cut marks will relate to a minimum number of cutting strokes, therefore many cut marks would imply many cutting strokes. However, the reverse is not also true. For example, one bone may have many cut marks and a second bone may have only one, yet they could have been butchered with the same degree of intensity (or number of cutting strokes).

It has also been suggested that cut marks on bone are more than accidental, but are an undesired by-product of butchering activities. Bunn (2001:207) proposed that, in order to preserve the sharpness of a stone tool edge, butchers would consciously avoid contacting the bone and stated that cut marks "are mistakes; they are accidental miscalculations of the precise location of the bone surface when muscle masses obscure it. As soon as the butcher can see the bone surface, few if any cut marks will be inflicted thereafter in that area". Conversely, Braun et al. (2008) have suggested that cut mark production is not reliably linked to tool edge attrition and therefore the production of cut marks would not have been consciously avoided during butchering because of this. They (Braun et al. 2008) found tool attrition to be more relatable to the butchering process being undertaken and that skinning and disarticulation cause greater tool attrition than defleshing activities. However, these experiments employed basalt flakes only and the methodology for determining wear and the subsequent evidence is unclear as no images are published. More research is needed to verify the reliability of these findings.

Guilday et al. (1962:64) proposed that cut mark frequency might be related to the skill of the butcher. One could argue that an experienced butcher would be in control of the knife and the butchering process at all times and would allow a tool to contact the bone surface only when it was somehow associated with the butchering process. Further, a butcher might not necessarily wish to avoid contact between knife and bone surface if such an action would sacrifice speed, efficiency, or gains from butchering. If the tool were dulled during use, it would then be a matter of sharpening it by retouching the edge. A process for which there is abundant archaeological evidence. However, this action requires time and, in the interest of efficiency, it would undoubtedly behoove a butcher to avoid contact with the bone if possible, regardless of whether this contact is the result of “accidents” or of intentional butchering practices.

In terms of location, it is important to remember that not all processing activities even have the potential to produce cut marks. However, if cut marks are created and preserved, there is some consensus as to the probable butchering activities associated with cut marks at specific locations. For example, skinning activities are typically associated with cut marks on the distal limb bones where the hide surface is near to the bone. Disarticulation cut marks are usually located on or near articular surfaces (Binford 1981b; White 1992). Scraping marks and short cut marks on the bone surface tend to be indicative of defleshing (Hurlbut 2000:7; Raemsch 1993; Olsen and Shipman

1994). However, further discrepancy exists because cut marks can often potentially be associated with more than one stage in butchering process.

Another difficulty in assessing cut mark frequency lies in the subjectivity of the identification and quantification process. As previously mentioned, the appearance of taphonomic equifinality is often related to the intensity of the methodology utilized in the analysis (e.g. degree of magnification). For example, according to Wickam (2005:Tables 4.1 and 4.2), the total EfPm-assemblage consists of 15, 737 identifiable *B.bison* specimens. The findings of the current research suggest that the cut marked assemblage represents a minimum of 2.4% of the total identifiable assemblage (not taking into account cut marks on unidentifiables). This is a more conservative estimate than Wickam's (2005:116) assessment of 4%. This discrepancy is most likely due to deterioration of the cut marked assemblage subsequent to Wickam's (2005) study as well as differences in analytical techniques employed including identification criteria and degree of magnification utilized.

There is also the potential for cut mark frequency to vary based on the tool material type employed. It has been implied that metal tools are more likely to produce cut marks than stone tools, as they will more easily cut through flesh and periosteum (Potts 1982:121 in Lyman 1987:267). Lyman (1987: 267) explores the potential for higher frequencies of cut marks in metal as opposed to stone tool cut assemblages by comparing several known sites. Although there is some evidence to suggest that this is the case, it is inconclusive, irregular, and there is much overlap. The myriad of factors that influence whether or not a cut mark is produced is complex. A single (albeit important) variable cannot predict it with any reliability based on current knowledge of butchery mark frequency. Lyman (1987:267) concludes that more research is needed before any sort of predictive models can be made.

Chapter 5

Methodology

5.1. Macroscopic Analysis

An initial macroscopic analysis of the EfPm-27 faunal assemblage was undertaken in the Public Archaeology Laboratory at the University of Calgary. Any faunal materials that were indicated to have taphonomic marks in the preliminary catalogue, supplied by Dr. Dale Walde, were separated out. In addition, a selection of identifiable and unidentifiable specimens was examined, and any bearing further taphonomic marks were separated. Catalogue numbers EfPm-27:200 through 844 were assigned to the collection and then submitted to the Royal Alberta Museum for clearance before being loaned to the University of Saskatchewan, Department of Archaeology for further analysis.

The next step of macroscopic analysis was undertaken with several objectives in mind. Firstly, to distinguish between cut marks and pseudo-cut marks; secondly, to identify potential metal and stone cut marks; and finally to identify cut marks that could potentially be used for SEM analysis. To accomplish these objectives, each element was examined for types of marks, including archaeological cultural marks, natural and post-depositional marks, as well as trauma.

Macroscopic analysis was undertaken with naked eye and hand lens inspection and low powered microscope analysis was carried out using a dissection microscope and strong, low incident lighting as suggested by Blumenschine et al. (1996). Cut marks were analyzed and recorded based on number of cuts, visibility and appearance, orientation, location, length, associations and associated breakage. Tool mark measurements were taken with a protractor and digital callipers. Information regarding provenience, element, portion, side, age, and sex if known was also cross-referenced with each catalogue number as well as any previous comments made by myself or others regarding the specimen. Observations on the intactness and fragility of the bone surface and the potential for use with the SEM were also made.

Identified cut marks were sketched with clearly indicated catalogue numbers on line drawings of the relevant bones and bone surfaces that were created using Microsoft Paint© (Appendix A). This is necessary to help identify cut mark distribution patterns and to link the results to the specific ecofacts (Shipman, personal communication, 2006). This technique has been employed in previous studies (e.g. Hill 2001, Savage 1995); this level of detail is necessary for reanalysis of the data used.

Macroscopic photographs were taken using a Nikon™ Coolpix 8800 digital camera, low powered light microscope photographs were taken with the same camera using a Nikon™ SMZ-2T dissecting microscope and a CamAdapter™ microscope camera adapter system with a step ring (CA64455 camera attachment kit). This allowed for a series of photographs of a mark to be taken to provide for maximum illustrative documentation of their appearance at the time of analysis (Figures 23 – 27). This is particularly important practice in cases where the bone surface is fragile and highly susceptible to potential trauma during cleaning or storage. In most cases, a macroscopic photograph including the entire mark and a microscope photograph of an illustrative section of the mark was considered sufficient documentation.

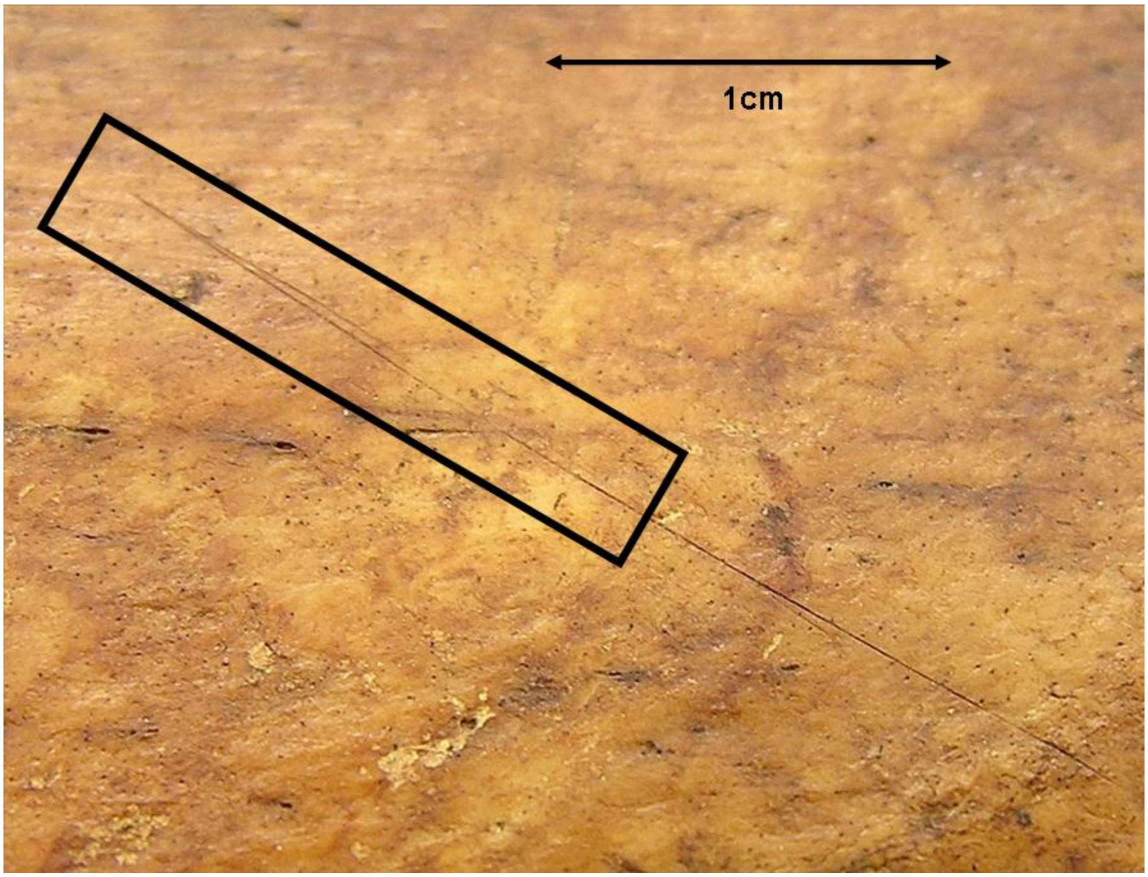

Figure 23. Macroscopic image of cut mark on spinous process of thoracic vertebrae Cat#373. Note shoulder effect on left end of cut mark. Rectangle highlights location of Figure 24.

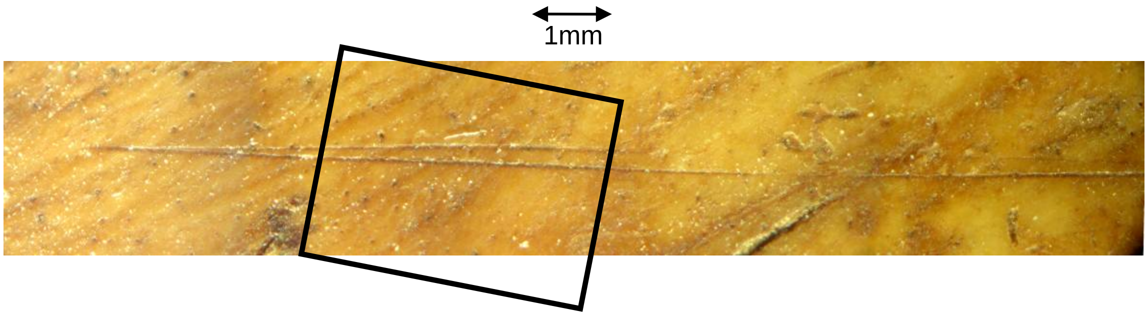

Figure 24. Panoramic microscopic image of cut mark from Cat#373 stitched from five individual photographs. Rectangle highlights location of Figure 25.

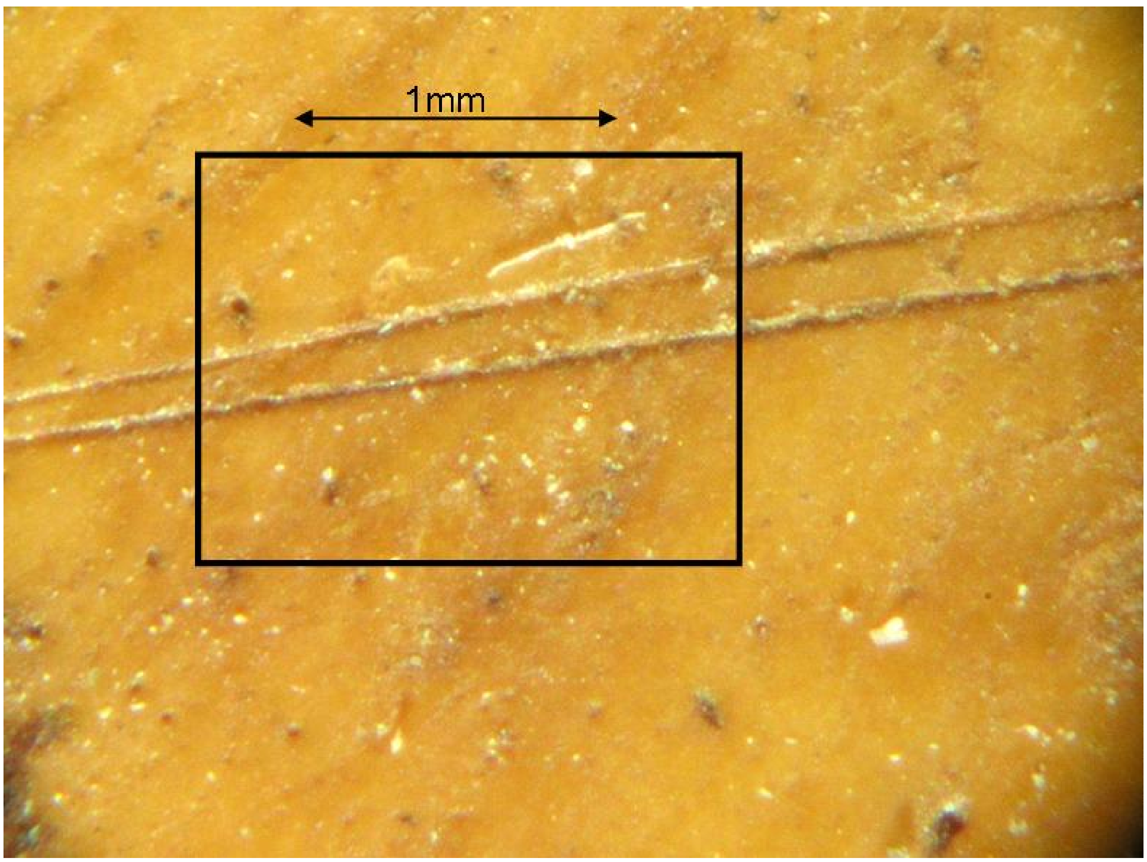

Figure 25. Microscopic image of cut mark from Cat#373 (x10 magnification). Rectangle highlights location of Figure 26.

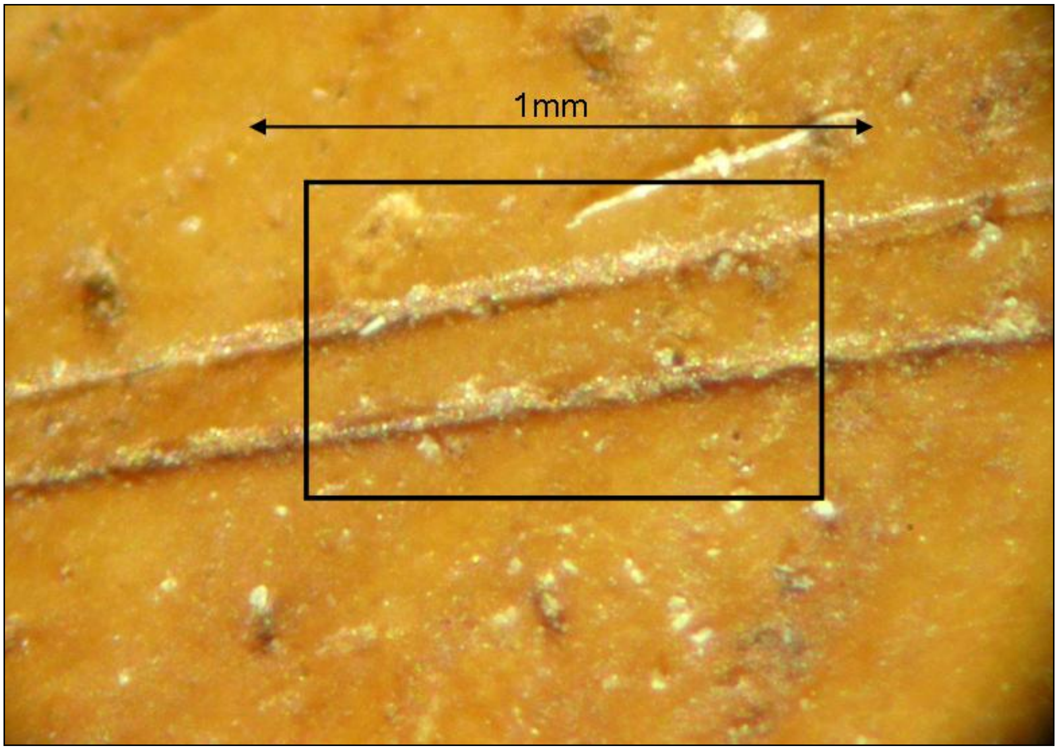

Figure 26. Microscopic image of cut marks from Cat#373(x20 magnification). Rectangle highlights location of Figure 27.

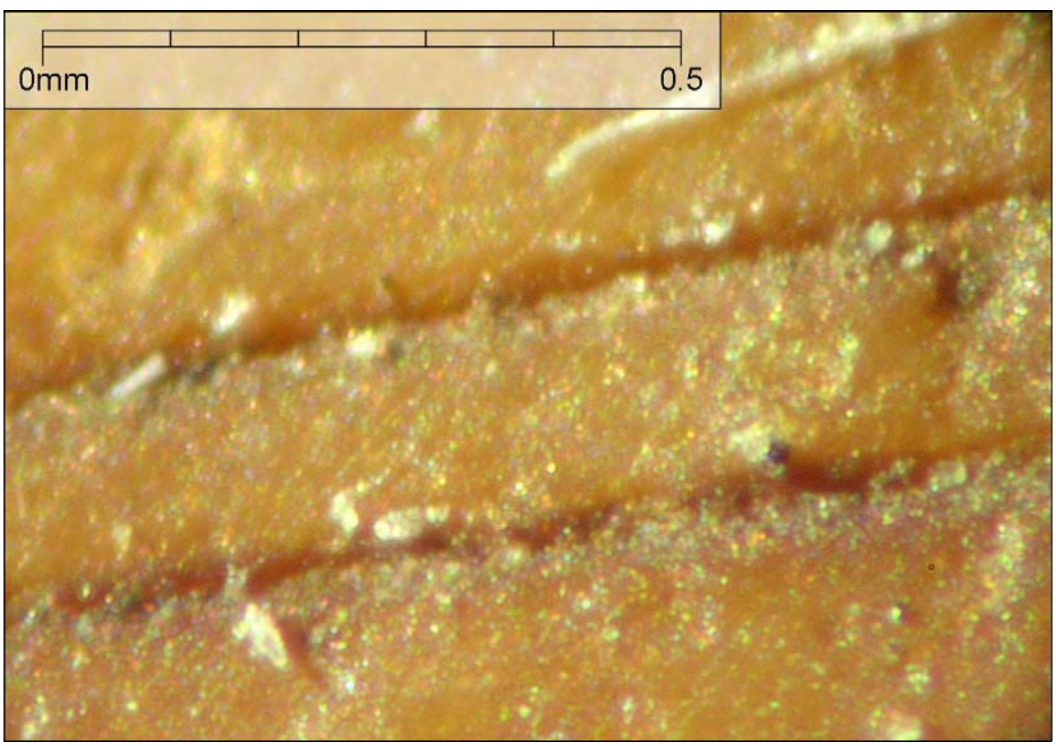

Figure 27. Microscopic image of cut mark from Cat#373 (x40 magnification). Note presence of sand grains.

5.2. Experimental Cut Marks

A comparative collection of twelve sets of experimental cut marks were created for this study (Table 7, Appendix B). These were made on the proximal end and shaft of a fresh cow tibia, the distal end having been sawed and removed by the butcher. The various lithics employed were flintknapped by Jason Roe and then immediately used to create the cut marks. All cut marks were made by hand while removing meat from the bone surface in an attempt to add a degree of authenticity. The process was photographed by Kim Wutzke and macroscopic and microscopic images of the experimental cut marks were taken by the author unless otherwise specified.

Table 7. Experimental Tool Marks

Set #	Material Type	Tool Type	Description
1	Obsidian	Unmodified flake	4 single cuts
2	Chert	Unmodified flake	4 single cuts
3	Chert	Unifacially retouched	4 single cuts
4	Obsidian	Unifacially retouched	3 single cuts
5	Chert	Bifacially retouched	3 single cuts
6	Obsidian	Bifacially retouched	2 single cuts
7	Chert	Serrated tool	4 single cuts
8	Chert	Unmodified flake	Multiple overlapping cuts
9	Chert	Unifacially retouched	Multiple overlapping cuts
10	Metal	Sharp flat knife edge	1 single cut; 1 set of multiple overlapping cuts
11	Chert	Scraper	Multiple passes
12	Obsidian	Scraper	Multiple passes

Unmodified, unifacially retouched, and bifacially retouched chert and obsidian flakes, as well as a serrated chert tool and obsidian and chert scrapers were created for this study (Figure 28). Fine chert and obsidian were selected as both these lithic types were discovered at EfPm-27 and these types were assumed to be the most likely lithic materials to create fine enough tools to macroscopically imitate metal tool marks. A modern metal knife was also used to create experimental cut marks. A series of single cut marks and concentrations of multiple cuts were made with all tools except for the scrapers. The scrapers both required at least two passes to create visible marks.

The distribution of marks were mapped and assigned numbers for ease of labelling (Figure 29). The sets were numbered sequentially in the order that they were created working from the distal end to the proximal end of the tibia. Each set of cuts was made with a single flake or tool (Figure 28).

Figure 28. Tools used to make experimental tool marks. Labelled left to right: Sets 1 – 6 (top row), Sets 7 – 10 (middle row), and Sets 11 – 12 (bottom row).

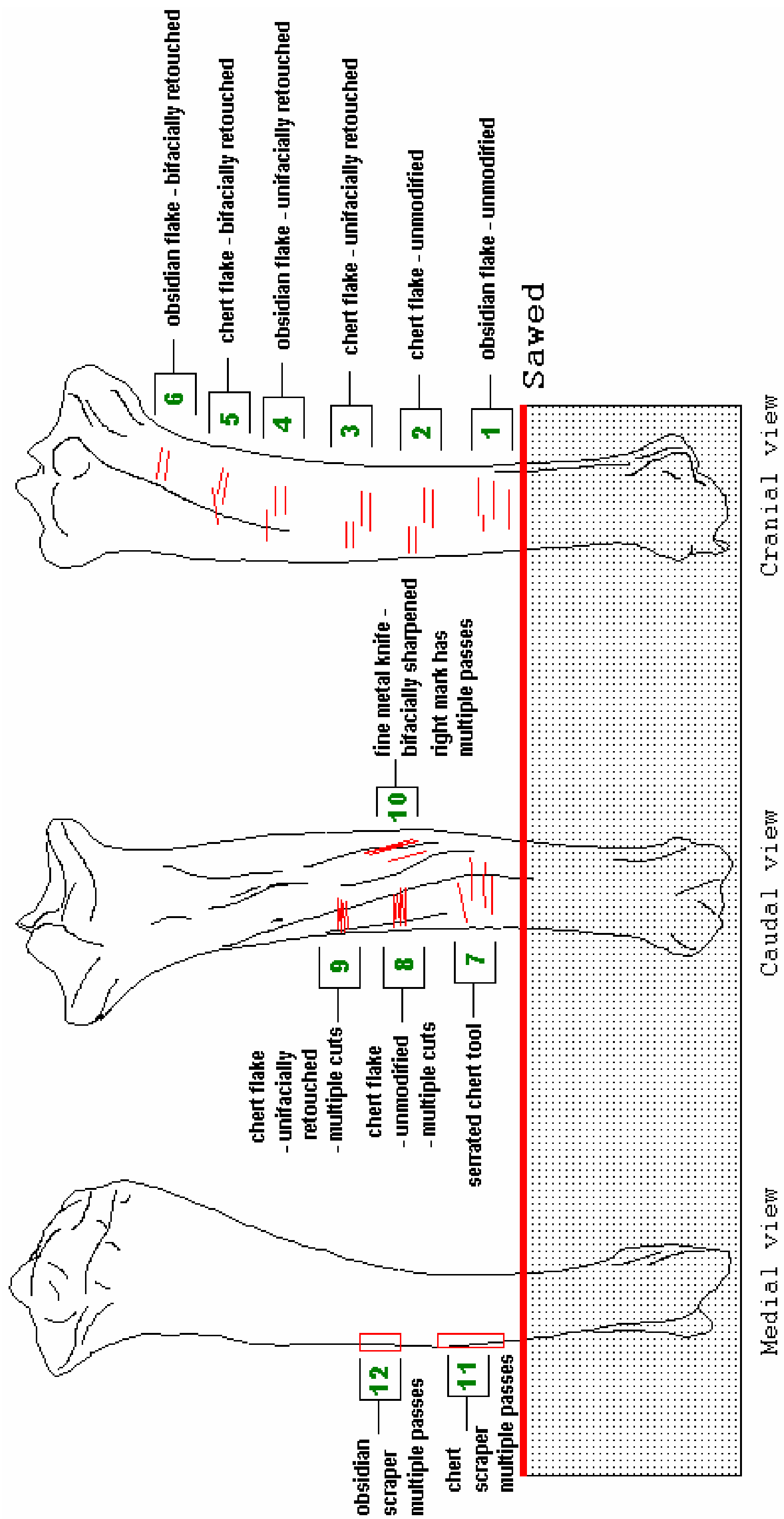

Figure 29. Distribution of experimental tool marks. Cut marks indicated by red lines. Stippled portions indicate absence of bone. Sets numbered sequentially in the order that they were created. Each set was made with a single flake or tool.

The tibia was then boiled and soaked in bleach to remove the excess flesh (Figure 30). This process has been shown not to "alter the gross or microscopic features of marks on bones" (Shipman and Rose 1988:306-307). Selected cut marks from Sets 1 through 6 were moulded with Xantopren® Comfort Light and the moulds were prepared for examination using the SEM in the same manner as EfPm-27 cut marks (described below).

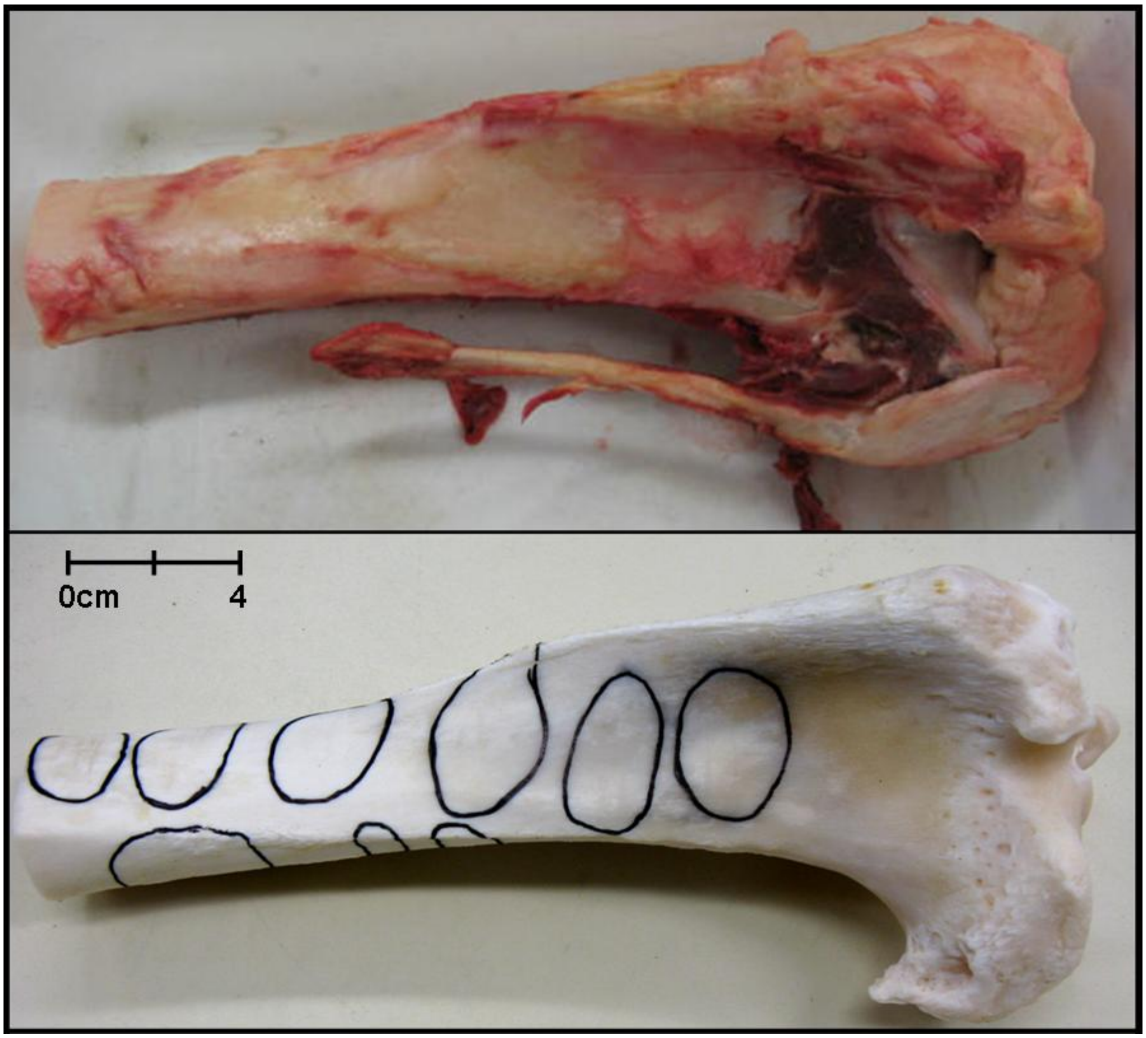

Figure 30. Two views of cranio-lateral surface of experimentally modified tibia: (top) pre-defleshing; (bottom) post-defleshing.

5.3. Historic Cut Marks

Cut marks from *Bos taurus*/*B.bison* elements from the Fort Walsh Townsite (DjOl-35) in the Cypress Hills were used as comparative metal cut marks. As mentioned above, these provided a higher potential for similarity with other archaeological marks than the experimental metal cuts produced. Suitable marks were selected from the sample using similar criteria to those previously mentioned for the EfPm-27 sample, while also taking into account the unambiguous nature of the metal origin of the historic cut marks. The marks were moulded with Xantopren® Comfort Light and the moulds were prepared for examination using the SEM in the same manner as the EfPm-27 cut marks (described below).

5.4. SEM Analysis

Cut marks identified during the macroscopic analysis as appropriate for SEM, were separated from the rest of the assemblage. Criteria included high cut mark quality and good surface integrity. The SEM analysis was completed in two trials using two different moulding products. Practice moulds for both trials were conducted on surfaces of both old and fresh non-archaeological bone specimens to test whether the material would cause damage to the bone surface. Next, marks from unidentifiable archaeological specimens were moulded in attempt to minimize impact to the assemblage should the moulding process result in damage (Figure 19). Finally, cut marks from selected identifiable specimens were moulded.

As noted in section 4.1, observations on the intactness and fragility of the bone surface were made to determine the potential of each cut mark specimen to withstand the moulding process in order to be examined with the SEM. Both Shipman (1981b:362) and Cook (1986:362) recognize the potential for adherence of mould material to a museum specimen being moulded for SEM examination. EfPm-27 contains many examples of identifiable cut marks with surrounding bone surfaces that were deemed too fragile or damaged to attempt moulding (Figure 31). Unfortunately, this characteristic removed several otherwise identifiable cut marks from the SEM analysis.

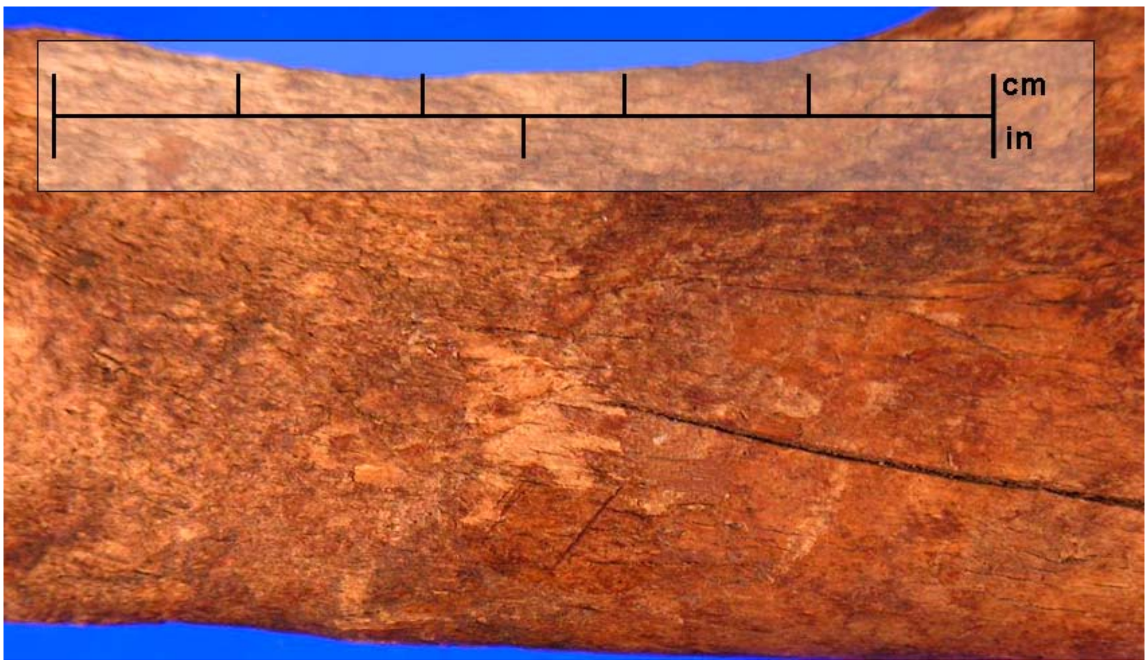

Figure 31. Macroscopic image of Cat#205 cut mark showing damaged and flaking surface that is too fragile to be moulded for SEM.

Due to time and budget constraints, only a limited number of samples could be analyzed, so an adaptive sampling procedure was followed. Information regarding the collection at the time of initial sampling suggested the presence of metal cut marks. Initial assumptions of the present study included the argument that it may not be possible to identify metal vs. stone cut marks in the assemblage without use of the SEM and, if so, any attempt at pre-identification could potentially bias later identification. Based on these factors, an initial sample strategy consisted of a small non-random sample of suitable marks from the entire assemblage taking into account the various macroscopically dissimilar cut mark specimens, and a random sample of suitable marks from the most common cut marked element type, thoracic vertebrae.

The initial research objective of comparing and contrasting metal and stone tool use at the site required the discovery of both cut mark types. The data gathered required an adaptation of the research objective to identification of the presence or possible absence of metal cut marks at the site. A final selection of specimens that had been previously deemed as having higher potential for being metal cut marks was made in an attempt to maximize the likelihood of identifying the presence of metal cut marks with the SEM.

The first trial was undertaken using Jeltrate® Plus, dustless, regular set, alginate impression material (Appendix C). Standard preparation procedure was followed using a ratio of 8 g of powder to 19 ml of water. This combination was mixed for at least 1 minute to get a creamy fluid paste and then applied to the bone surface using a spatula. At least 4 to 10 minutes of set time was allowed before moulds were removed from the bone surface and placed in clean, labelled, plastic bags.

The second trial was undertaken using Xantopren® Comfort Light, C-silicone (condensation silicone) impression material (Appendix C). The prepared cartridge of Xantopren®, containing separate component materials comprising the base paste and matching catalyst paste was inserted into an automatic 4:1 ratio dispensing gun. The components were combined within the attached disposable applicator tip. The material was then applied to the specimens' surface and removed when dry after several minutes.

An initial consultation with a dental hygienist indicated that a combination moulding process utilizing Xantopren® with Optosil® putty as a physical base might be advisable. This method was attempted but not pursued as it was found to affect the moulds negatively (Appendix C).

For both the Jeltrate® Plus and Xantopren® trials the original negative moulds were analyzed as it has been suggested that positive replicas from the negative moulds would be too far removed from the originals to be reliable, since detail may be lost and the potential for imperfections increases with each subsequent replicative step (Greenfield, personal communication, 2006). Greenfield's (1999) methodology differs from others, such as Shipman and Rose's (1983a, 1983b), mainly in its use of negative replicas. Cross-sections of marks were also examined to a limited extent, but were not considered a priority due to their dubious interpretative applications.

Along with the cut mark moulds, a sample of the Jeltrate® Plus powder and control samples of the Xantopren® Comfort Light, Optosil® putty, and combination Xantopren® with Optosil® moulding materials were prepared. The negative moulds and control samples were brought to the SEM laboratory for preparation by laboratory technician Tom Bonli.

During preparation, each specimen was glued to a labelled specimen stub and then moisture evacuated. Since SEM imaging requires samples to be analyzed under vacuum to reduce interference by air molecules, samples cannot contain a significant amount of moisture. Any moisture would become vapour under electron irradiation, which would compromise the vacuum and be detrimental to the electron beam. Once dried, a thin layer of gold or gold palladium alloy was applied using low vacuum sputter coating. This process causes the specimens to be electrically grounded to prevent accumulation of electrostatic charge on the specimen during electron irradiation and electronically conductive on the surface to reduce scanning faults and image artifacts.

The SEM functions by firing a stream of electrons, which are focused by electromagnetic lenses, towards an object (Mead and Meeks 1989:277). Electrons within the surface of the object are released under this bombardment and "are amplified and shown on a high-resolution television type screen" (Mead and Meeks 1989:277). Digital image captures of the live view of the black and white screen can then be taken; the images appear in greyscale because colour is a function of visible wavelengths (Mead and Meeks 1989:277-278).

Digital images were captured of each examined specimen at various settings and locations. All SEM images were taken by the author unless otherwise specified. Magnification level was selected at greater than x50 to prevent vignetting. Coarse and fine focus must be adjusted to reveal desired features and increase image sharpness. Contrast and brightness can be manipulated to produce the best digital image. In the microscope the tilt, rotation, and lateral position of the specimen can be moved for optimal orientation. All cut mark samples were initially inserted pointing towards the centre of the machine. Orientation, settings, and date were recorded for each image to allow for future repetition of examination if necessary.

Chapter 6

Results

6.1. Macroscopic Analysis

6.1.1. Results of Macroscopic Analysis

During the macroscopic analysis, all unambiguous cut marks on identifiable bones from the assemblage were individually sketched on bone diagrams. Appendix A lists the selected mapped cut marks (Table A1) and gives the distribution diagrams for each cut marked element (Figures A1 – A19). A total of 222 bones with cut marks were mapped from a collection of approximately 414 possibilities (Table 8). The difference consists of unidentifiables and rib shaft fragments, which could not be mapped (N = 146), as well as probable cut marks that were damaged or otherwise inconclusive. The remainder of the 651 elements catalogued for this study from the larger EfPm-27 faunal collection exhibited pseudo-cut marks, rather than cut marks, or they appeared compromised to the extent that cut mark identification was inconclusive or impossible.

Multiple forms of tool marks were present in the assemblage, including chopping and impact marks (Figures 6 and 7), as well as multiple forms of cut marks (e.g. Figures 10-12, 14, 22, 31). Many examples of specimens with multiple concentrations of cut marks (Figure 32) and several examples of associated elements with continuous cut marks, primarily vertebrae (e.g. Figures 10 and 12), were also observed (Table A1). Several marks in the EfPm-27 assemblage (Figures 13-14) reveal an asymmetrical and angled appearance observable with both low-powered microscopy and SEM. Shoulder effects are evident in experimental marks produced for the current study, particularly Set 2 (Figure B16) and in some specimens in the EfPm-27 assemblage (Figures 11 and 23-24).

Table 8. Frequencies of Potential and Mapped Cut Marked Specimens

Element	**# of potential cut marked specimens**	**# mapped specimens**
1st phalanx	3	0
2nd phalanx	1	1
Astragalus	8	6
Atlas	1	2
Calcaneus	1	1
Cervical vertebrae	1	0
Cranium	2	2
Dentary	21	17
Femur	9	8
Humerus	5	2
Hyoid	6	6
Intermediate carpal	1	1
Lumbar vertebrae	13	10
Metacarpal	3	2
Metatarsal	5	5
Os coxa	14	8
Radius	8	3
Rib	121	21
Scapula	2	1
Thoracic vertebrae	131	121
Tibia	10	5
Ulna	2	0
Unidentifiable	46	0
Total	**414**	**222**

Figure 32. Two views of Cat#226 showing cut marks on two separate locations of the same element: (top) macroscopic image of cuts on the horizontal ramus below M_2 on the medial surface of the left dentary; (bottom) macroscopic image of cuts on the medial surface of the diastema.

As previously indicated, several forms of pseudo-cut marks were evident in the assemblage including rodent gnawing (Figure 17), root etching (Figure 18), trauma (Figures 5, 21, 22, and 33), weathering (Figures 6, 15, 20, and 31), and carnivore gnawing (Figures 16 and 34). However, the several examples of overlapping or closely associated pseudo-cut marks and cut marks are of specific significance. In particular, an instance of carnivore punctures superimposed over cut marks indicates scavenging by canids after the butchering event (Figure 34). In addition, Figure 33 highlights an instance of trowel trauma in close proximity to cut marks while Figure 31 reveals an example of a cut mark that is partially removed by weathering.

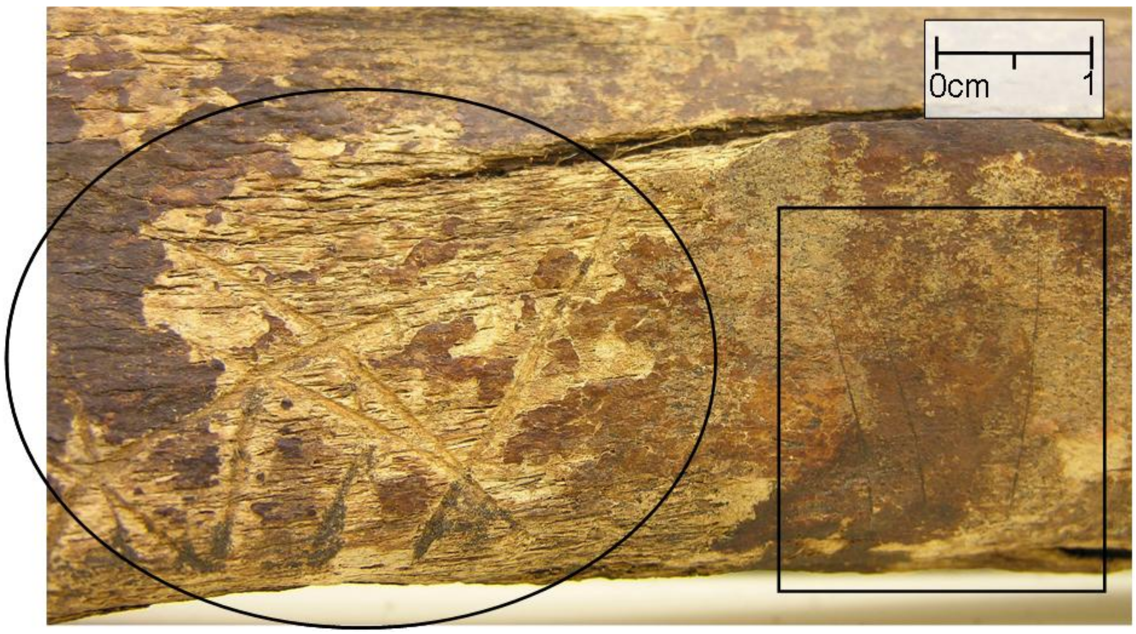

Figure 33. Macroscopic image of Cat#343: oval highlights trowel trauma marks and rectangle indicates location of cut marks on spinous process of thoracic vertebra.

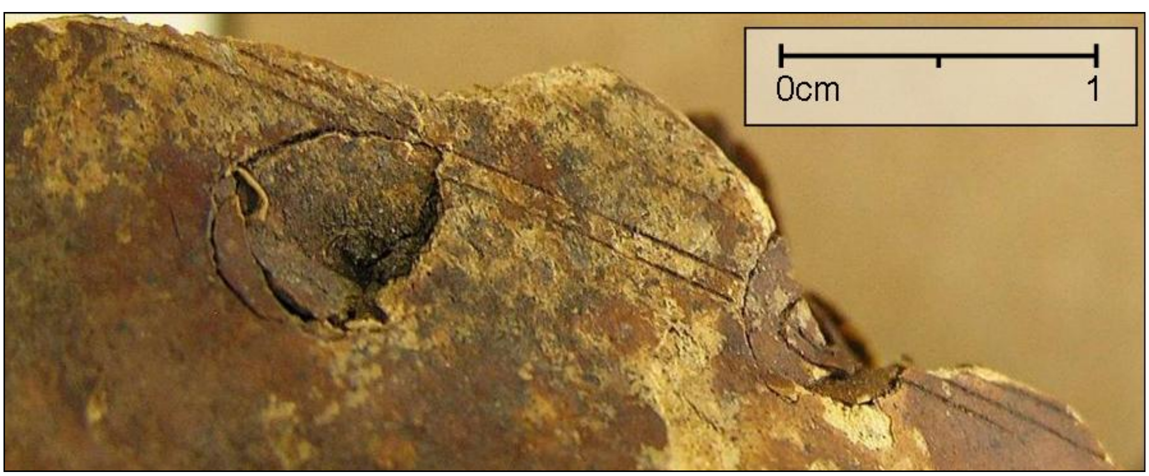

Figure 34. Detail macroscopic image of Cat#342: spinous process of thoracic vertebra with carnivore tooth punctures overlapping cut marks indicative of canid scavenging.

6.1.2. Sources of Error

It is necessary to identify as many potential sources of error as possible in an attempt to recognize and compensate for potential biases. In terms of cut mark morphology, cases of misidentification and misinterpretation are common and often difficult to avoid, especially if a specimen is in poor condition. Carnivore gnawing marks (Figure 33), trauma (Figure 34), and surface deterioration (Figure 31) were all found in close association with cut marks in the assemblage. It is likely that similar scenarios could have completely removed the cut mark or previously existing bone surface, especially in the case of deterioration and trauma.

It is also possible that marks that currently appear to be trauma originally appeared as cut marks when first inspected prior to undergoing cleaning and storage (Figure 5). The EfPm-27 assemblage was initially cleaned by field school students with toothbrushes, usually by dry brushing but also employing wet brushing. Wet brushing and aggressive dry brushing can easily obliterate all traces of damage morphology. Even gentle dry brushing has been shown to cause microscopic damage, even if macroscopic damage is not visible (Bromage 1984). It must be borne in mind that the microscopic characteristics of any of the cut marks could have been damaged or obliterated during the cleaning process. However, this variable could not be controlled and was unavoidable under the circumstances.

6.2. Experimental Cut Marks

6.2.1. Results of Experimental Cut Mark Production

Upon defleshing and macroscopic inspection, Sets 7 through 12 were deemed to be too macroscopically dissimilar from the EfPm-27 cut marks to warrant examination using the SEM. This included the examples of metal cut marks, which contributed to the conclusion that historic metal cut marks would be a more constructive comparative sample than the experimental metal cuts. This may have been due to the use of a steel blade rather than an iron one. Only the individual marks created with blade tools were examined using the SEM (Table 7, Figures 29 and 35). Images of the experimental process, tool marks produced (Figures B1-B10), and SEM images of Sets 1 through 6 (Figures B11-B29) can be found in Appendix B as well as Figures 28-30 and 35.

Idiosyncrasies of the tools used became evident upon examination with the SEM. Cut marks from Sets 2 and 3, in contrast to Sets 1 and 4, are much sharper and cleaner in their appearance reflecting the greater resilience of chert compared to obsidian blades. The crumbled appearance was much more visible in the live image for Set 4 than on the captured images, which are marred by charging (Figures B23-B24). However, as was found by Greenfield (2006:154), the unmodified obsidian cut marks from Set 1 were the thinnest, smoothest marks compared to the coarser or more modified tools from the other sets.

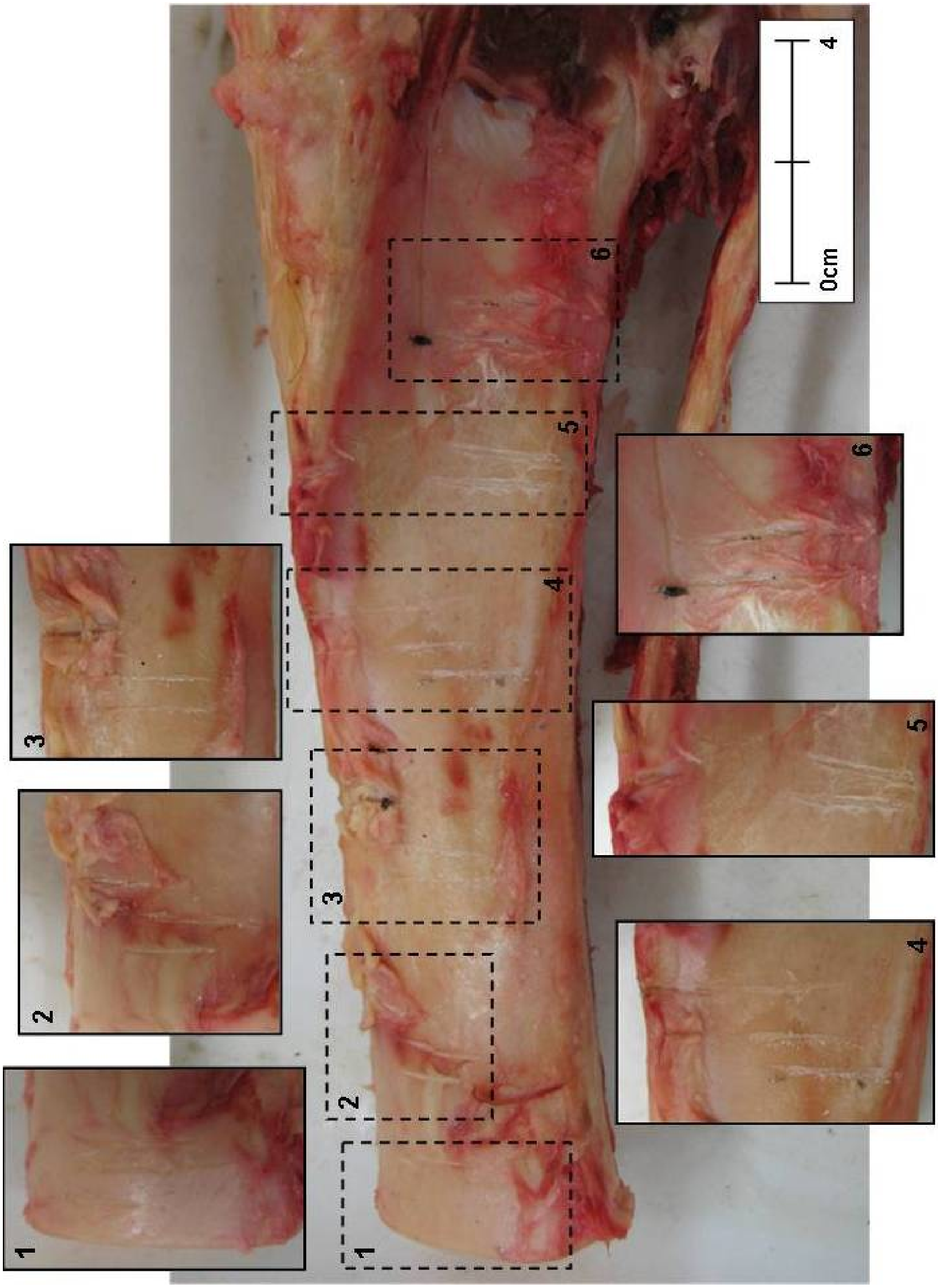

Figure 35. View of cranio-lateral surface of fresh tibia showing experimental cut marks Sets 1 through 6 and inset detail macroscopic images.

Images of Set 3 reveal wide V-shaped cut marks that reflect their unifacial modification, showing a smooth side on the right and a rough side on the left of the image (Figures B19–B21). Sets 5 and 6, the bifacial tools, showed a stronger edge with more resistance to crumbling, but left much more complex marks than the unmodified and unifacially modified flakes (Figures B25-B29). The resultant SEM images clearly mimic the predicted features for bifacial tools suggested by Walker and Long (1977) described in Chapter 4.2. The marks from Sets 5 and 6, as well as Set 2, show very distinct ancillary longitudinal striae and ridges.

6.2.2. Sources of Error

It was not possible to imitate a true butchering pattern with the resources at hand. Haynes (1991:163) has suggested that some stone-tool butchery experiments may not produce valid or realistic examples that are comparable to archaeological cut marks because the experimental marks may be "much larger and deeper and more sharply incised than many true cut marks made by humans who habitually butcher game animals''. However, intentional, forced tool marks, while not representative of the specific archaeological method of occurrence, have been used in multiple archaeological and forensic comparative studies. These experimental marks should accurately reflect the form of the tool and be morphologically comparable to archaeological tool marks. Even so, caution must be taken because the experimental marks will tend to be more distinct, cleaner, and deeper than the average archaeological mark because of both the intentional force applied and the taphonomic processes affecting the archaeological specimens.

6.3. Historic Metal Cut Marks

6.3.1. Results of Historic Metal Cut Mark Examination

The historic cut marks sampled appeared very deep but relatively similar macroscopically to fine cut marks from the Fish Creek assemblage. The SEM images reveal them to be very fine and regular (as well as deep and angular) in appearance, with no fine striae evident (Figures 36 and 37). This compares favourably with examples of metal cut marks from other studies (e.g. Greenfield 1999, 2002).

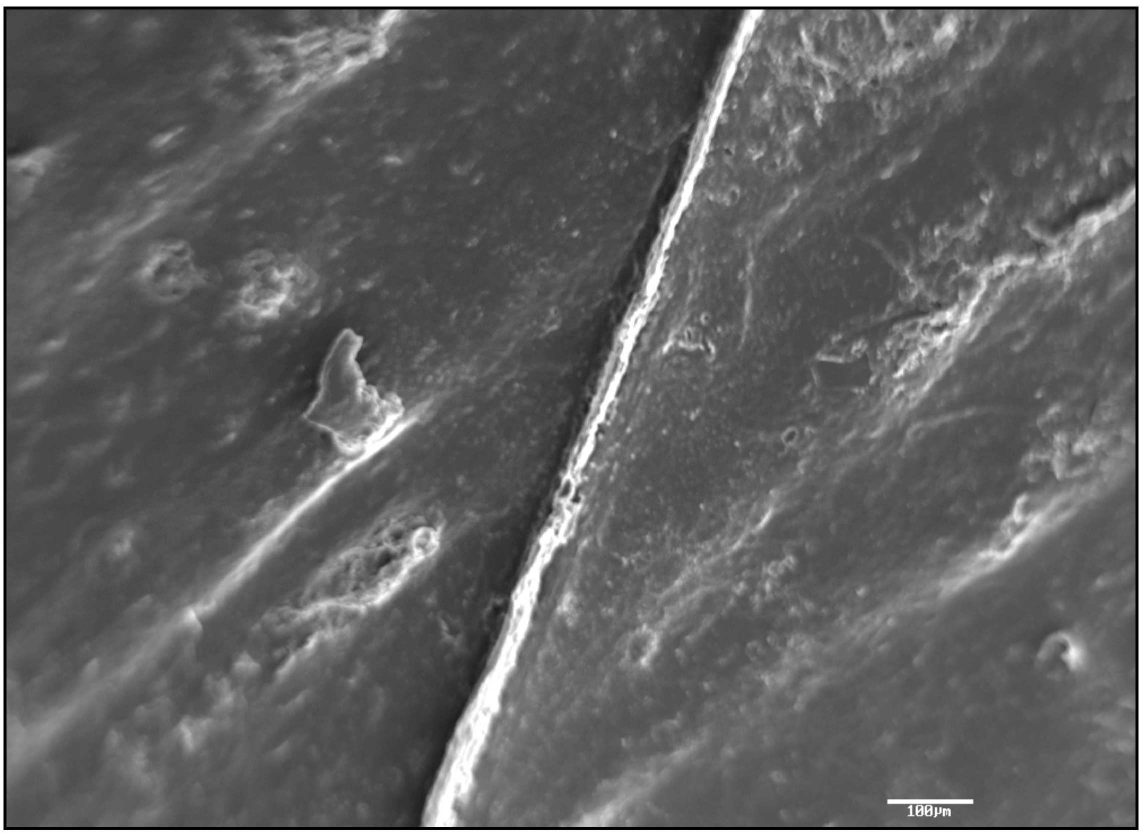

Figure 36. SEM image of historic metal cut mark from DjOl-35 (Fort Walsh Townsite) (x100 magnification).

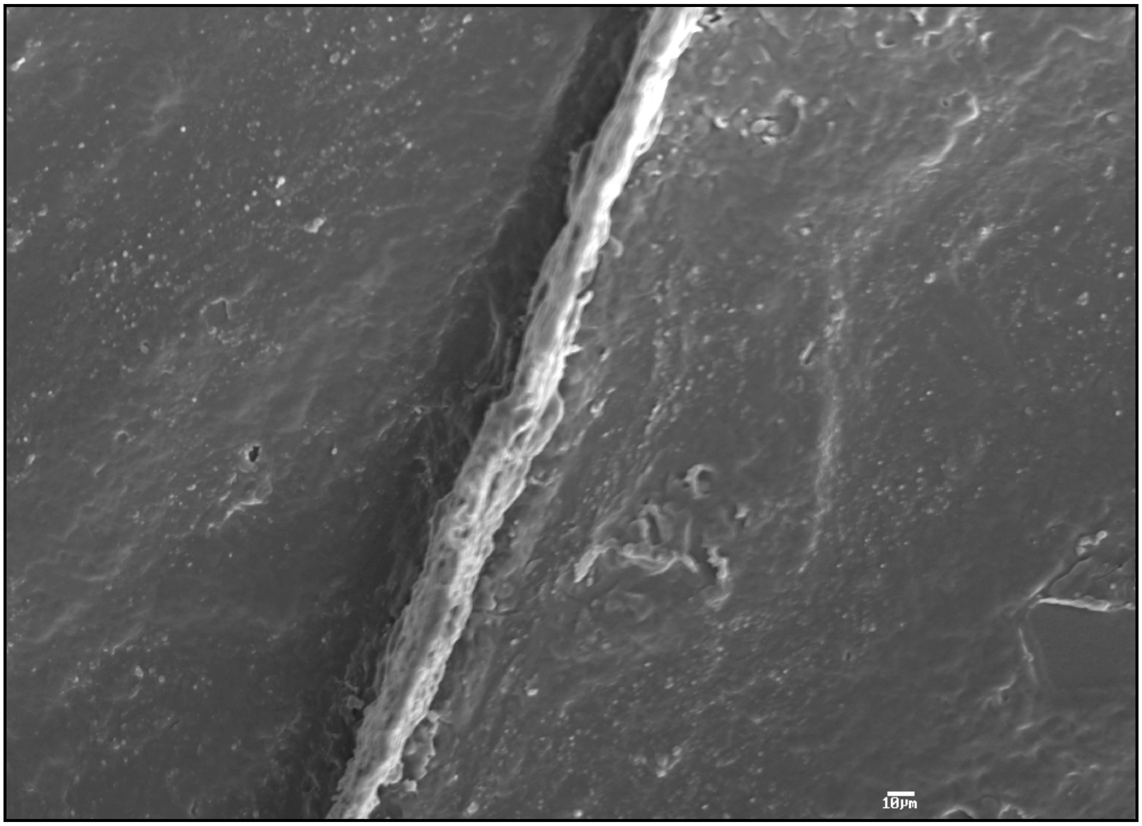

Figure 37. SEM image of historic metal cut mark from DjOl-35 (Fort Walsh Townsite) (x300 magnification).

6.3.2. Sources of Error

The historic cut marks used are susceptible to the same sources of error defined as the EfPm-27 specimens. Although it is a historic sample with clear metal cut marks, the exact tool and methodology of production of the historic sample is unknown. This is a major difficulty when using archaeological material as comparative samples.

6.4. SEM Analysis

6.4.2. SEM Analysis of EfPm-27 Cut Marks

The EfPm-27 cut marks analyzed with the SEM were all identified to be most likely the product of stone tools. This was due to the majority of these marks exhibiting features that most closely resembled identified features of archaeological and experimental cut marks known to have been produced by stone tools (as described in Chapter 3). However, several samples were ambiguous in their morphology, associated with physical damage to the cut mark or the mould or with various sources of SEM error.

Approximately 16% of the total cut marked assemblage was examined beneath the SEM. Several elements yielded multiple useful moulds. Tables 10 and 11 list the moulds and images produced for selected samples; specimens listed in these tables that do not appear in Table A1 are comprised of unidentifiables.

Of the 68 Jeltrate® moulds created, 26 of them either failed during the moulding process or were subsequently damaged. Of the 40 Jeltrate® moulds analyzed with the SEM, a further 14 were revealed to be damaged or otherwise failed to produce useful SEM images (usually due to excessive charging or disruptive imperfections) (Table 9). These were on 32 separate Cat#s with 22 separate Cat#s providing useful SEM images. Other than these mechanical failures, most of the Jeltrate® images could not be used for metal vs. stone identification. The coarseness of the moulds allowed them to reflect only gross morphology. Appendix C describes the critical comparison and observations made of the mould materials used in this research.

Table 9. Cut Marks Moulded with Jeltrate® and Processed for SEM.

Jeltrate®		
Cat#	**Moulds Processed for SEM**	**SEM images**
226	2	yes
231	2	yes
268	2	yes
373	1	yes
403	1	no
433	1	yes
602	1	yes
604	1	yes
605	1	yes
642	1	yes
645	1	no
658	3	2 yes / 1 no
663	1	yes
664	2	1 yes / 1 no
675	1	no
677	1	no
683	1	yes
685	1	no
690	1	yes
712	2	1 yes / 1 no
733	1	yes
736	1	yes
737	1	no
739	2	1 yes / 1 no
740	1	yes
741	1	yes
746	2	1 yes / 1 no
820	1	no
821	1	no
833	1	no
844	1	yes
Total	40	26 yes / 14 no

Table 10. Cut Marks Moulded with Xantopren® and Processed for SEM.

Xantopren®		
Cat#	**Moulds Processed for SEM**	**SEM images**
200	1	yes
205	1	yes
207	1	yes
208	1	yes
209	1	yes
210	1	yes
212	1	yes
215	1	yes
216	1	yes
218	1	yes
220	1	yes
226	3	yes
227	1	yes
228	1	yes
229	1	yes
231	3	yes
233	1	yes
236	1	yes
237	2	1 yes / 1 no
239	1	no
252	1	yes
254	1	no
255	1	yes
260	1	yes
261	1	yes
263	1	yes
266	1	yes
268	1	no
277	1	yes
304	1	yes
305	1	yes
306	1	yes
308	1	no
309	1	yes
311	1	no
315	1	yes
316	1	yes
317	1	yes
Total	43	37 yes / 6 no

Of the 57 Xantopren® moulds made of EfPm-27 cut marks, 14 failed during the moulding process and 43 were processed for the SEM (Table 10). Of the 43 moulds processed, one was found to be damaged when more closely examined, two were damaged when they broke off their stands before they could be examined, and 4 failed to produce useful SEM images due to excessive charging. These were on 38 separate Cat#s with 33 of these providing useful SEM images.

Figure 38 shows Cat#220, a typical cut mark specimen with sharp, fine features and a deep kerf. These features create a macroscopically ambiguous origin. Figures 39-43 show SEM images of multiple views and magnifications of the cut marks present. These SEM images clearly reveal stone tool mark morphology including longitudinal striae and rough, blunt kerf apexes. Figure 44 shows Cat#212, a more weathered specimen, also with macroscopically deceptive features. Figure 45 shows an SEM image of the cut mark on Cat#212 indicating a shallow mark with observable irregular striae.

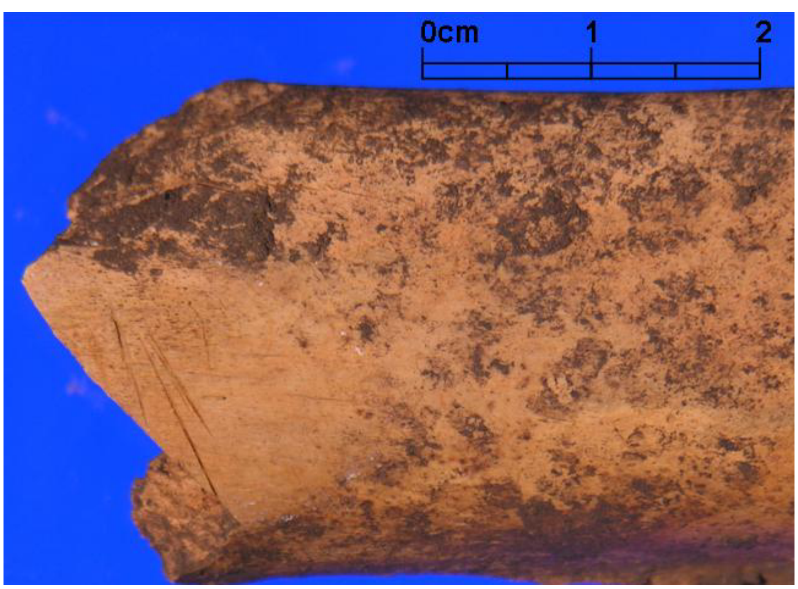

Figure 38. Macroscopic image of Cat#220 showing cut marks previously identified as potentially metal.

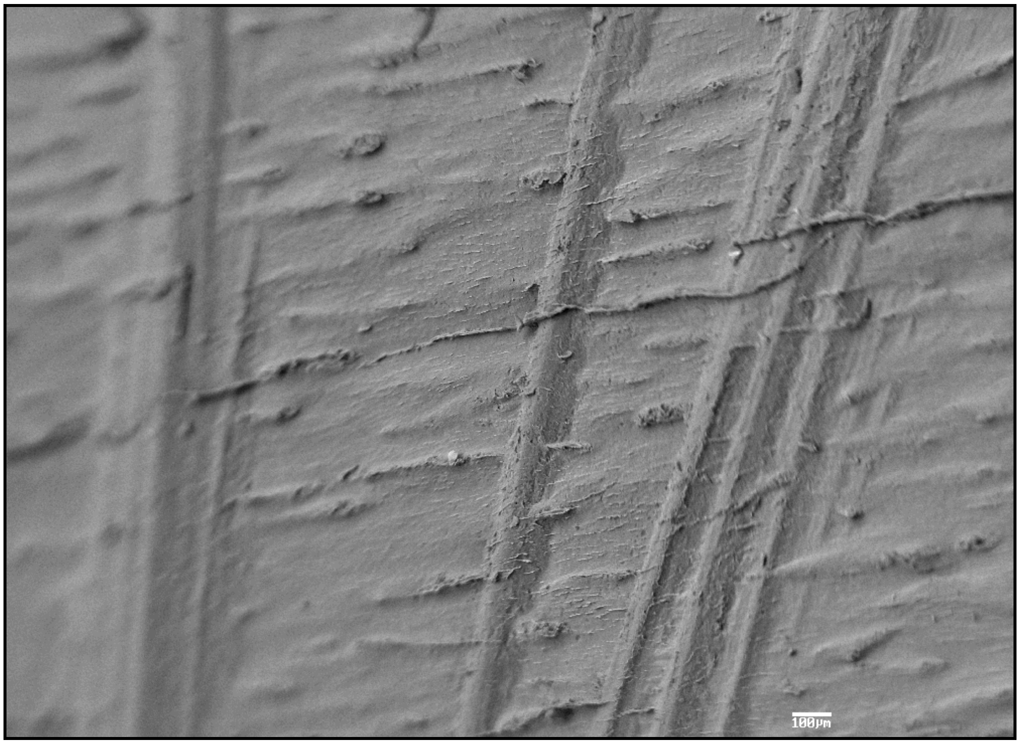

Figure 39. SEM image of Xantopren® mould of cut marks on Cat#220 (x50 magnification).

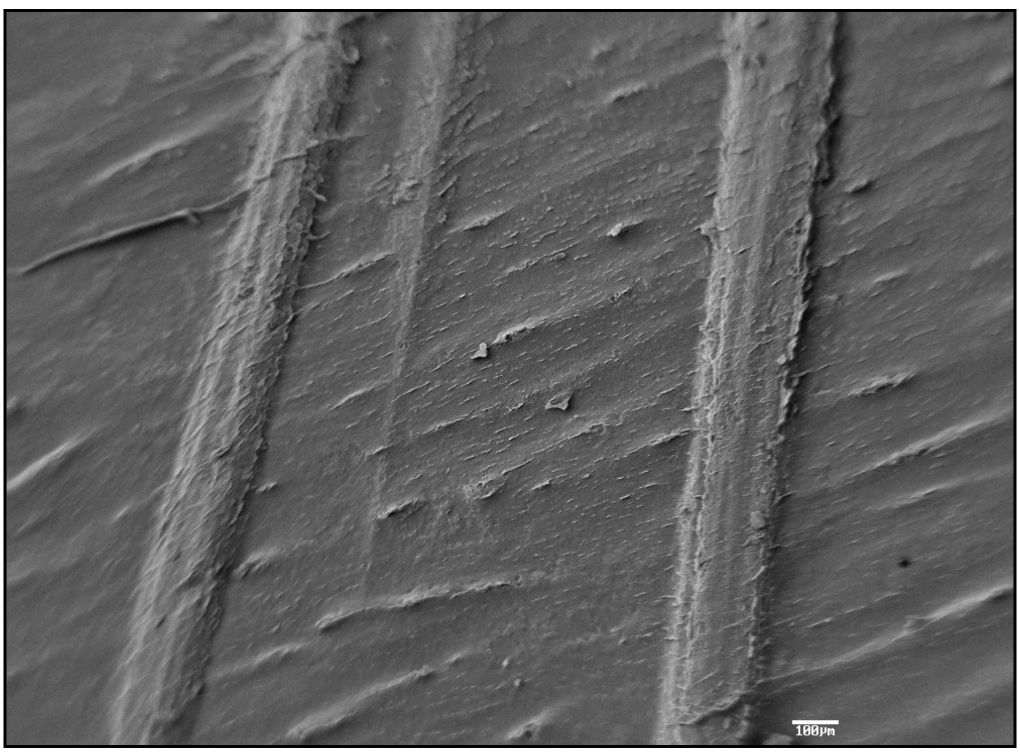

Figure 40. SEM image of Xantopren® mould of cut marks on Cat#220 (x60 magnification).

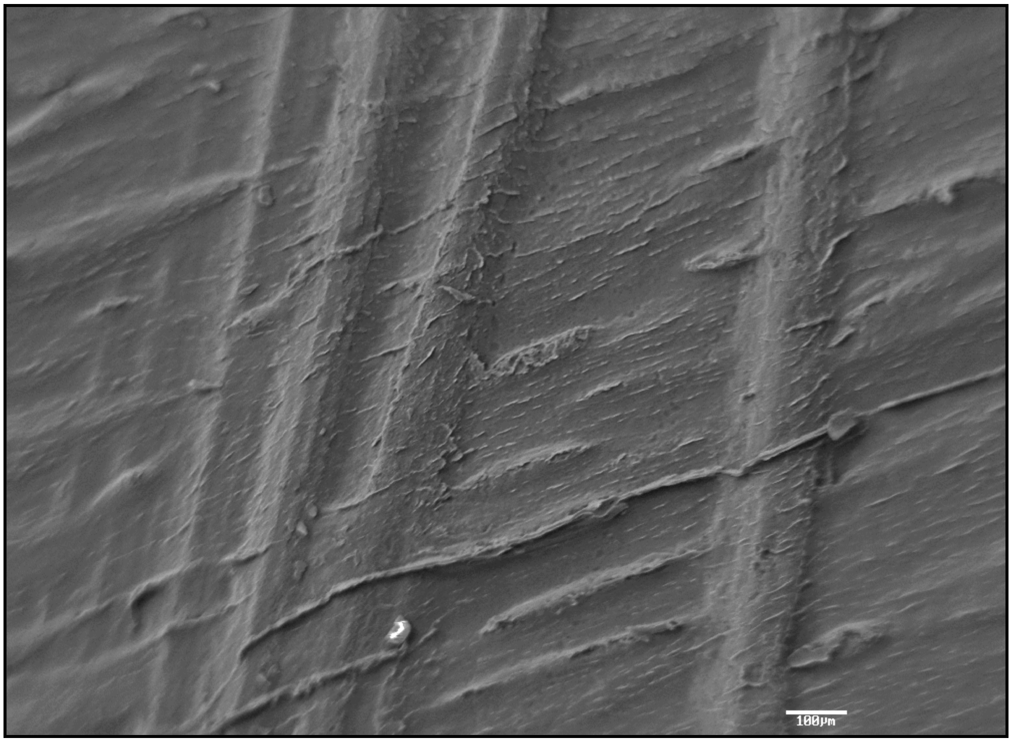

Figure 41. SEM image of Xantopren® mould of Cat#220 cut marks (x80 magnification).

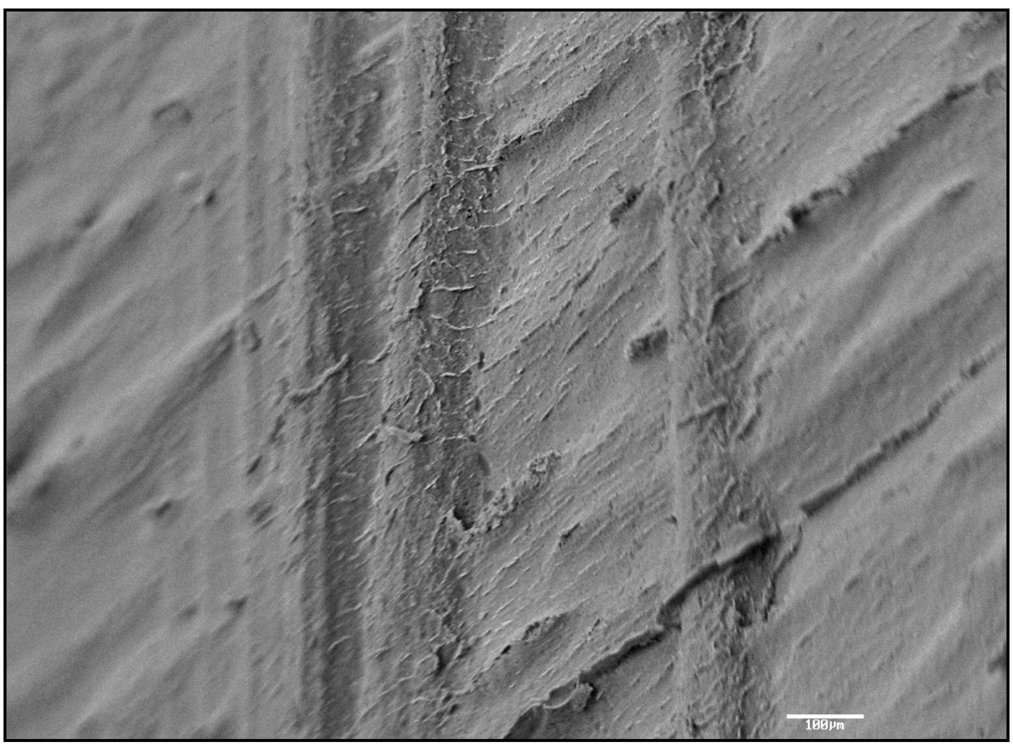

Figure 42. SEM image of oblique view of Xantopren® mould of cut marks on Cat #220 (x100 magnification).

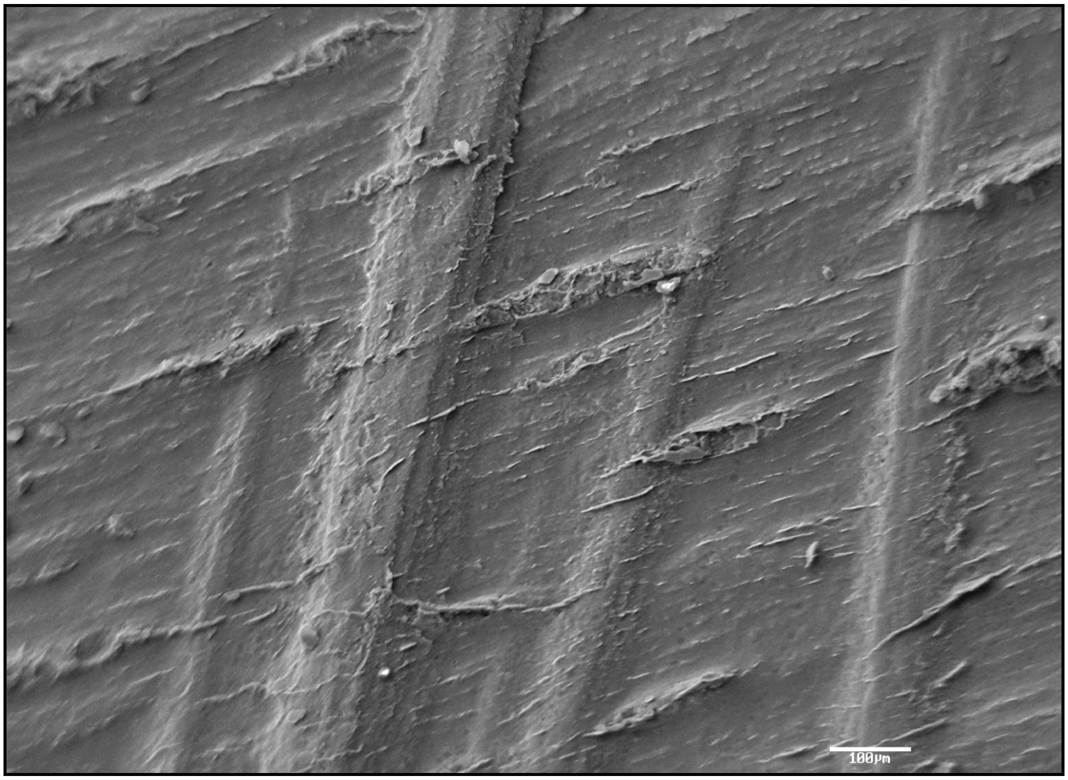

Figure 43. SEM image of Xantopren® mould of cut marks on Cat#220 (x100 magnification).

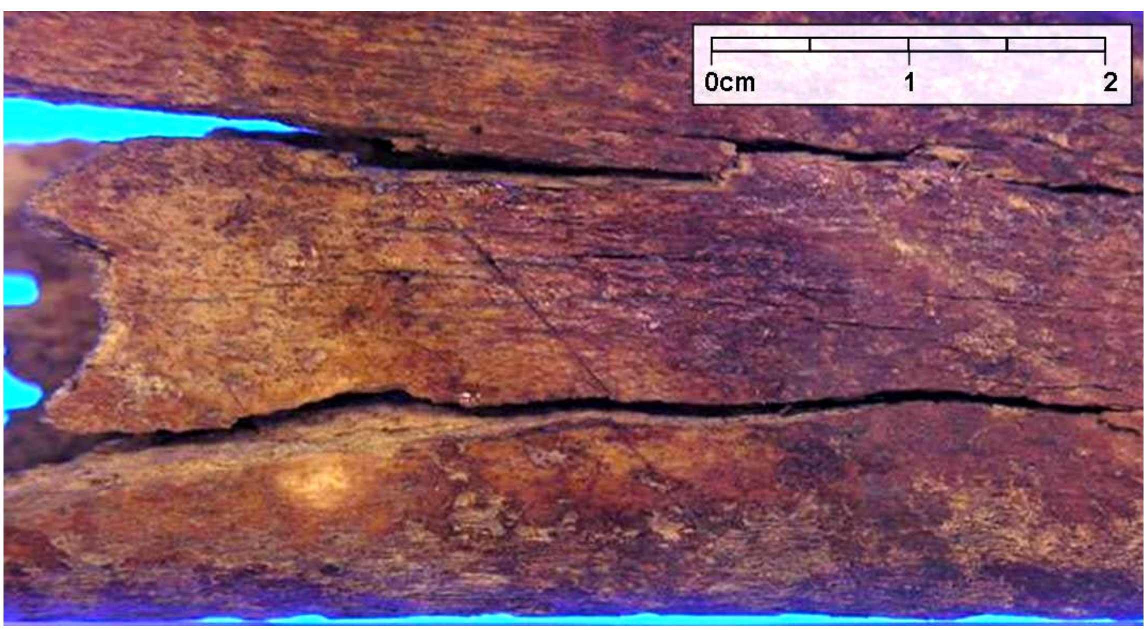

Figure 44. Macroscopic image of Cat#212 showing cut mark broken by weathering cracks.

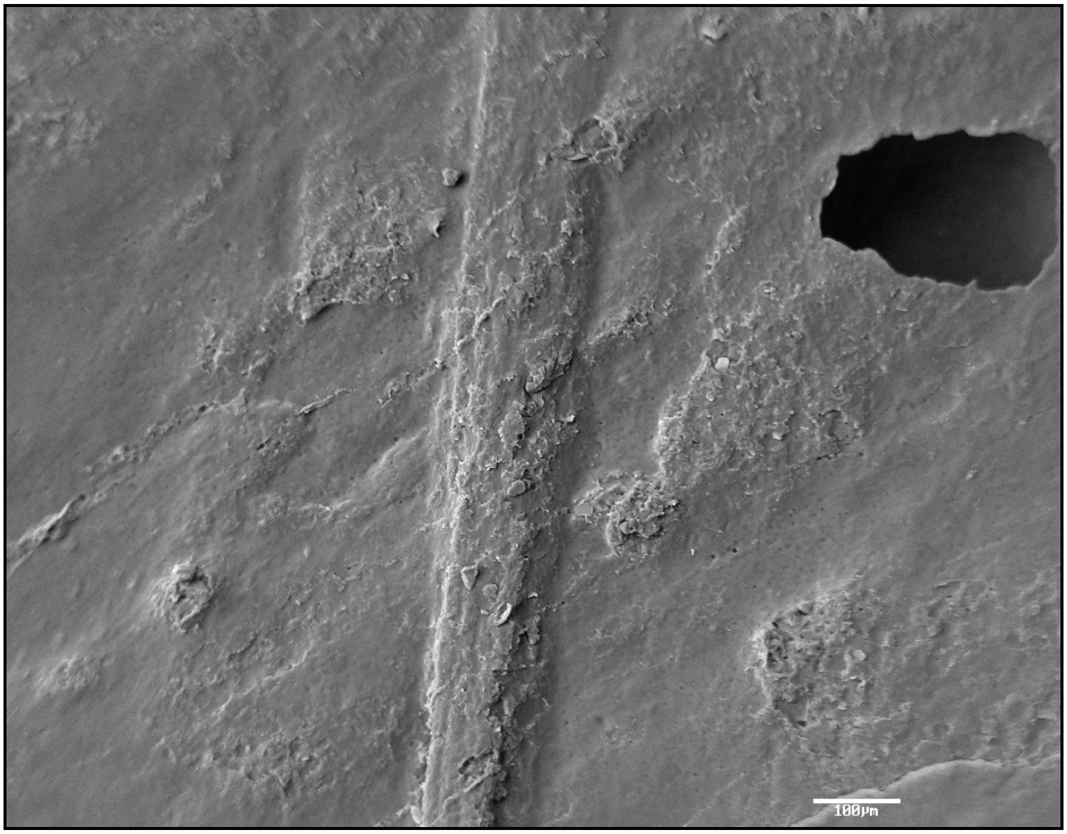

Figure 45. SEM image of Xantopren® mould of Cat#212 (x100 magnification) showing cut mark (vertical, centre) and air bubble (top right).

The concern of repeatability of mould analysis was addressed by examination of several of the marks at multiple points in time. The same mould of one mark was examined at different points in time. Figure 46 shows an SEM image of the Xantopren® mould of the cut mark on Cat#277 taken on November 14, 2007 and Figure 47 shows the same mark and location taken on January 5, 2007. This is the same angled cut mark shown in Figure 13. The Xantopren® material showed no deformation or deterioration over time. In addition, relocation of the same position on the mark was a simple task even without the use of recorded orientation information.

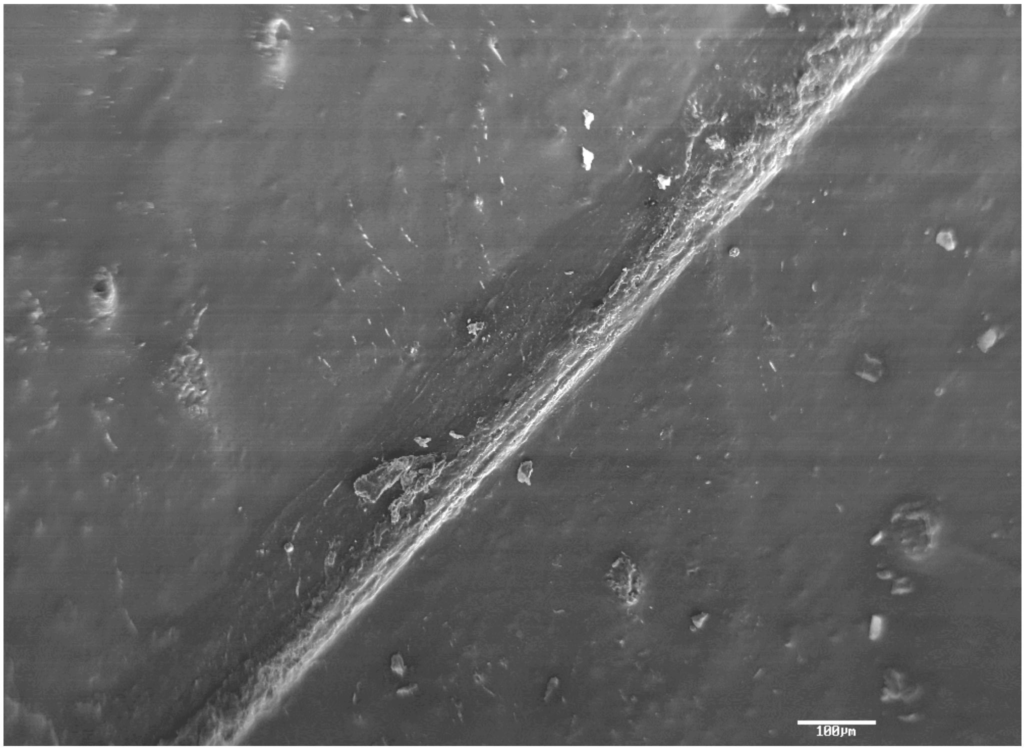

Figure 46. SEM image of Xantopren® mould of Cat#277 (x100 magnification) taken November 14, 2007.

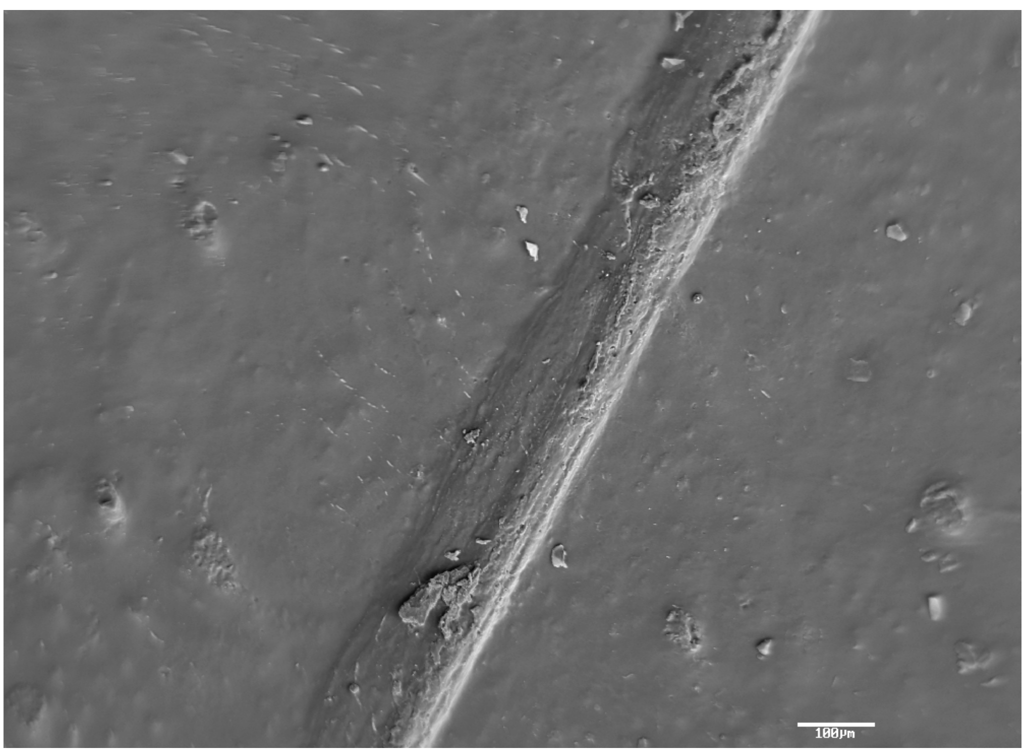

Figure 47. SEM image of Xantopren® mould of Cat#277 (x100 magnification) taken January 5, 2007.

6.4.3. Sources of Error

Identification was accomplished using known identifiable features of stone and metal cut marks, published data and images (Table 1), and experimental comparative samples. Besides the previously mentioned difficulties associated with the use of experimental cut marks, using published data as a comparative sample can be problematic. Often, published SEM images are difficult to interpret or are photocopied images of poor quality. Difficulties also arise when using studies that employed positive replicas of cut marks and pseudo-cut marks (e.g. Potts and Shipman 1981), rather than negative moulds (e.g. Greenfield 1999, 2000, 2002, and 2006) as in the present study.

Several issues arose regarding the documentation of SEM images. There is a discrepancy between captured images and screen view for some specimens. While the screen image is a constantly changing live view, the image capture is scanned in subsequent rows of pixels over a period of several minutes. Often brightness, contrast, and even focus were difficult to gauge on the live view as to how the saved image of the view would appear. In addition, the orientation of the sample within the SEM would have a significant effect on the image produced (Figure 48). This could be advantageous for highlighting desired features at a certain angle, but sometimes a specimen would be excessively shadowed or produce charging at one angle but not at another. Greenfield (1999:799) notes that "[w]hen viewed from directly overhead (90° angle), cut-marks lose their shape and depth". This was often the case with the current study, so angled views were preferentially captured if possible.

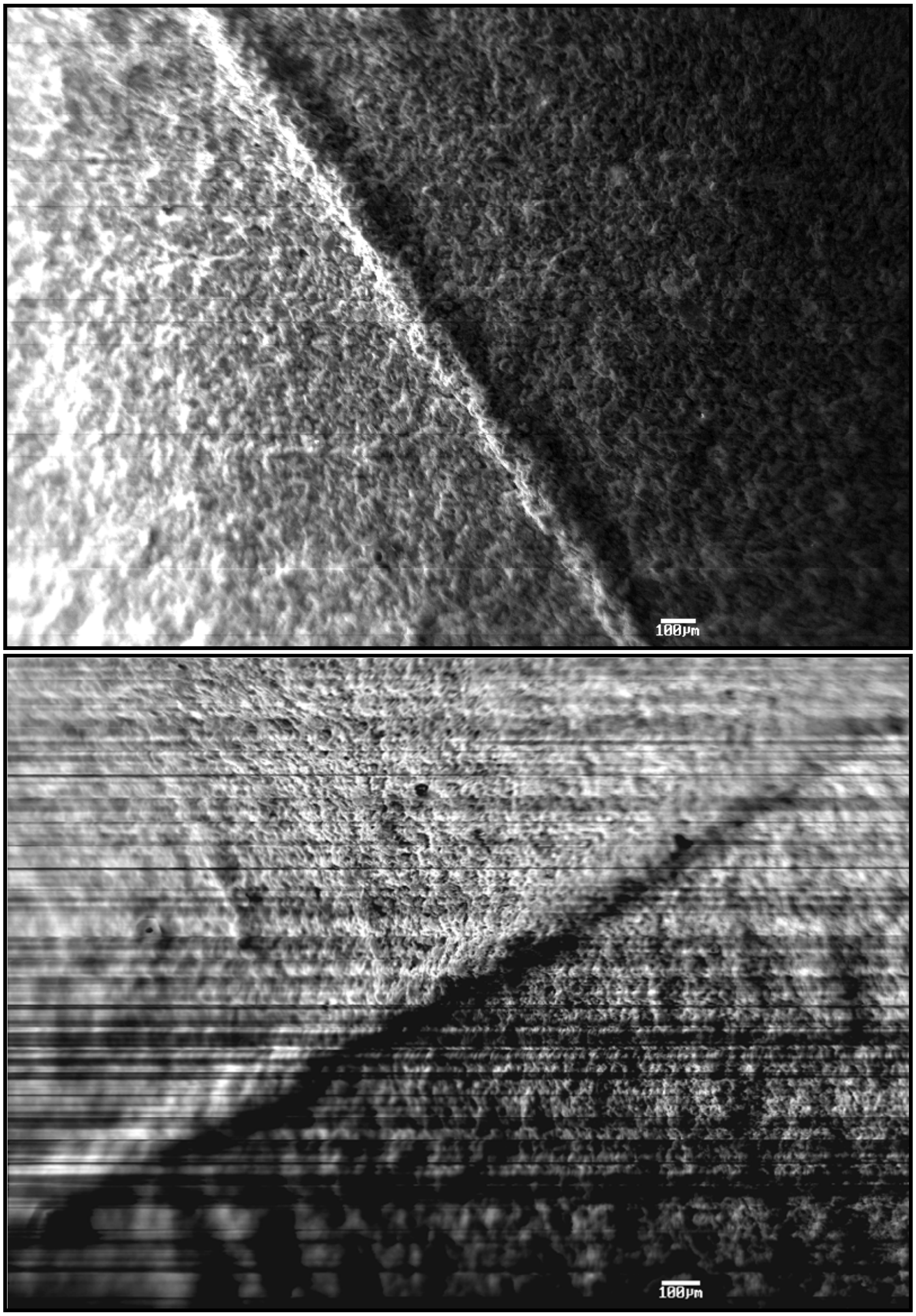

Figure 48. SEM images of Jeltrate® mould of Cat#677 at contrasting angles: (top) tilt = 37.5 and rotation = 52.5 (x50 mag.); (bottom) tilt = 43.9 and rotation = 79.1 (x55 mag.).

The issue of charging was a recurring problem. Charging results from the flow of electrons across the sample surface in the SEM being impeded in some way. This is often a result of dust or moisture presence, or can be due to an imperfect or damaged gold coating on the specimen and can be solved by recoating the specimen. The Xantopren® moulds remained flexible over time (Appendix C), which was useful in terms of mould production and lack of warping, but, if the mould is accidentally deformed this potentially cause damage to the gold coating, resulting in excessive charging in the SEM images. Hard moulds would be resistant to this problem.

Mild charging is not necessarily a hindrance in terms of the live image because it varies so rapidly that it is difficult to see. However, since the image capture is built in a series of rows from moments in the live image, the image capture will often be marred by streaking (Figure 48), a wavering image (Figures 49 and B24), or contrast changes or variation (Figure 50). The image in Figure 50 in particular was perfectly clear and of uniform brightness and contrast on the view screen but the image capture differed markedly. Charging can sometimes be significantly reduced by increasing the probe current. This will cause the live image to become very grainy or show "snow", but the image capture will be of higher quality (Figures 49 and B23).

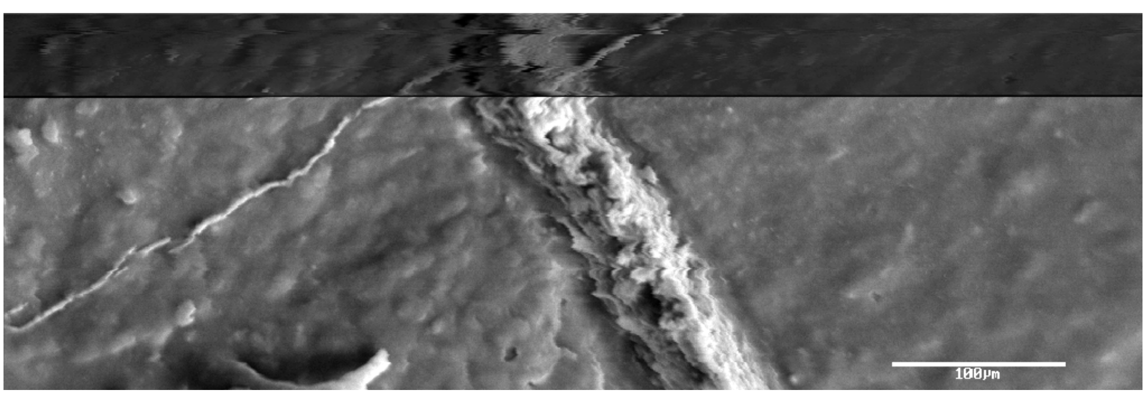

Figure 49. SEM image of Xantopren® mould of experimental Set 1 (x200 magnification) showing probe current changes: (top) dark band had low probe current but good visibility on the live image; (bottom) bright band had high probe current but very poor visibility on the live image.

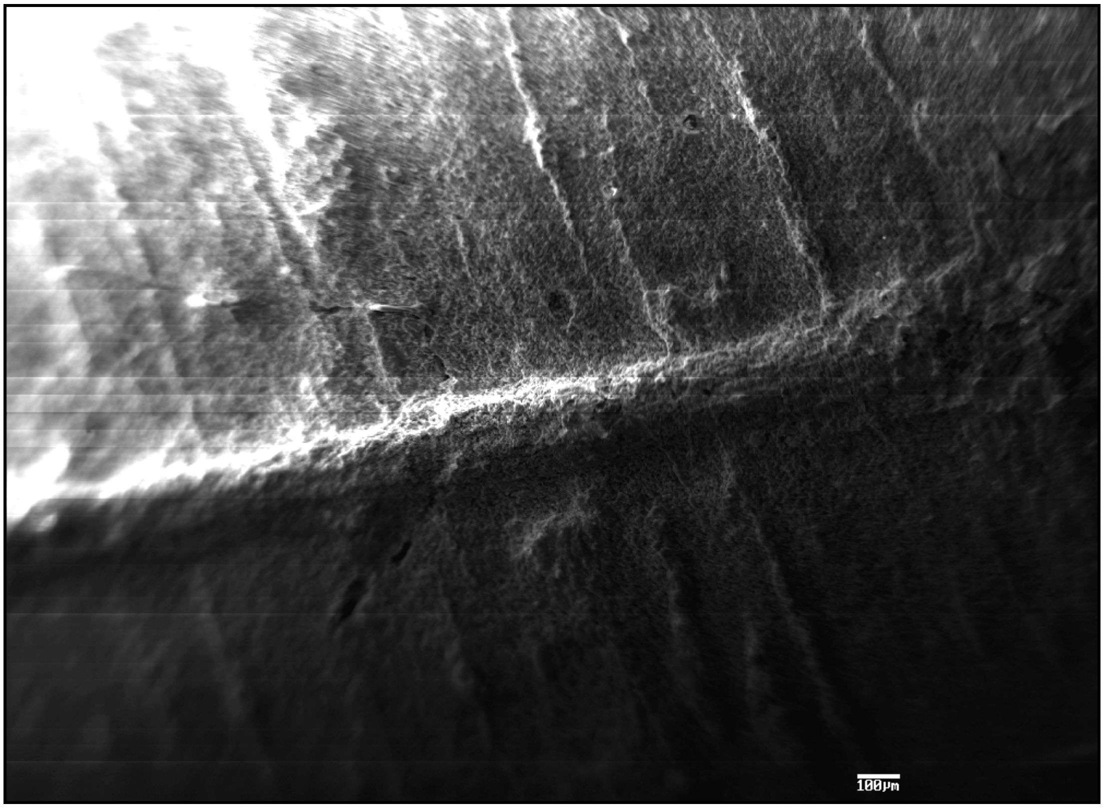

Figure 50. SEM image of Jeltrate® mould of Cat#664 (x50 magnification) cut mark: showing charging and contrast variation that was not evident on the live image.

Imperfections such as dirt grains or air bubbles would sometimes appear in the mould. Dirt grains causing imperfections in the gold coating will appear as a bright point of light or a dark shadow with a bright centre. Air bubbles are found in many of the moulds. These appear as irregularly shaped, dark voids and are rounded in cross-section (Figure 45). Pseudo-cut marks such as weathering cracks or root etching are occasionally moulded along with the cut mark. These features will sometimes mask portions of the image or the cut mark but they are easy to recognize and should not be confused with genuine features of the mark. Figure 51 illustrates these imperfections by showing air bubbles, a dirt particle with a surrounding shadow, and root etching going across 2 cut marks in the bottom right corner.

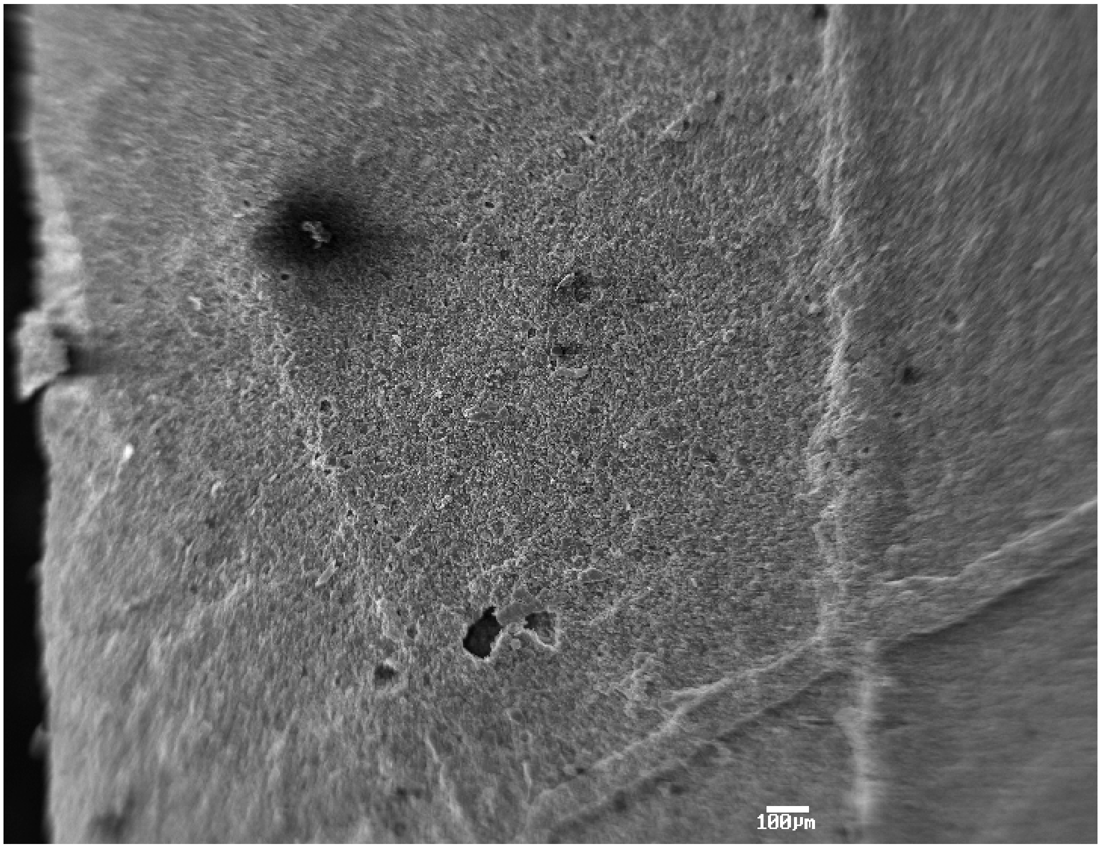

Figure 51. SEM image of Jeltrate® mould of Cat#739 (x45 magnification): shows cut marks and multiple imperfections. Low magnification results in lack of focus around image edges.

Damage to the mould itself is generally recognizable during mould production and these moulds can be discarded or flagged. Jeltrate® moulds tended to have a much higher rate of failure in this regard than Xantopren® moulds. Mould damage will cause the mark replica to be unreliable, especially in the damaged areas, but this damage is recognizable when viewed with the SEM (Figure 52). This will differ from the appearance of an intact mould of damaged cut mark specimen (Figures 53-54).

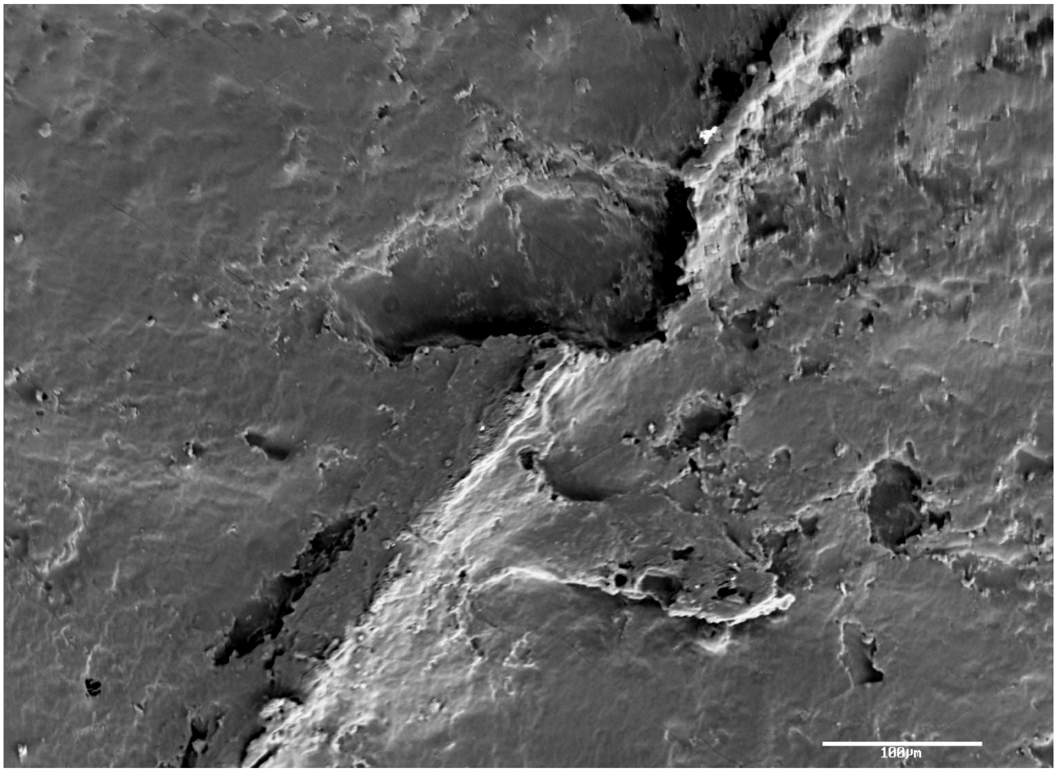

Figure 52. SEM image of damaged Xantopren® mould of Cat#260 (x200 magnification).

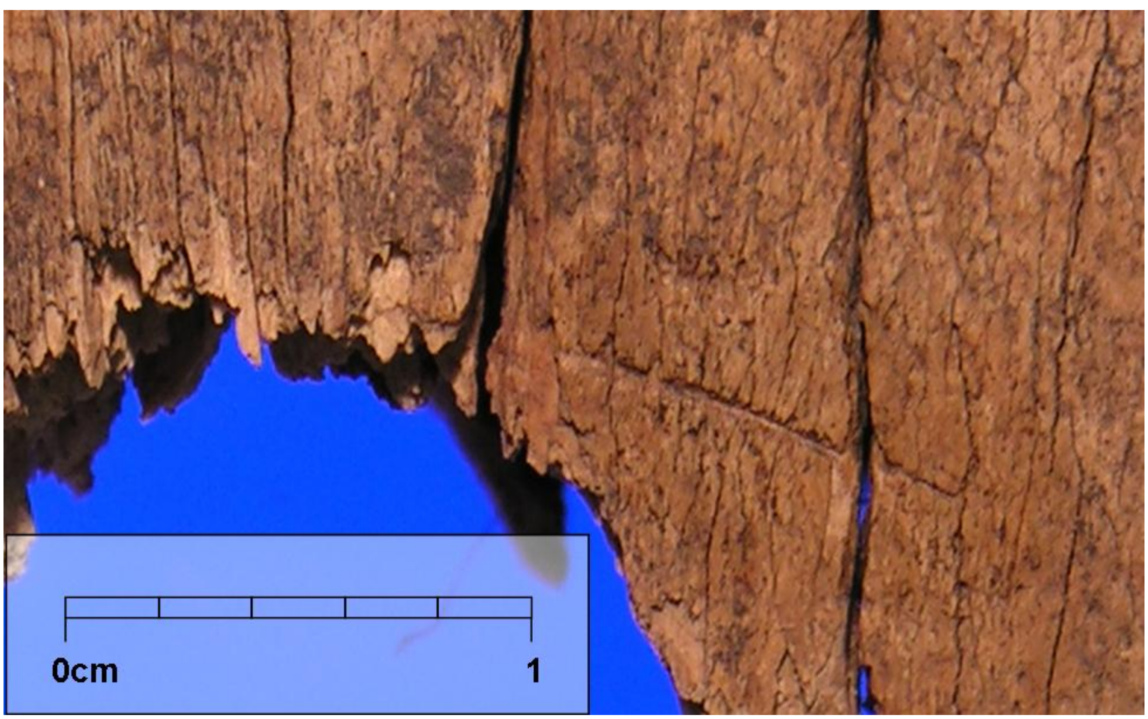

Figure 53. Macroscopic image of Cat#210 showing weathered cut mark on broken section of dentary.

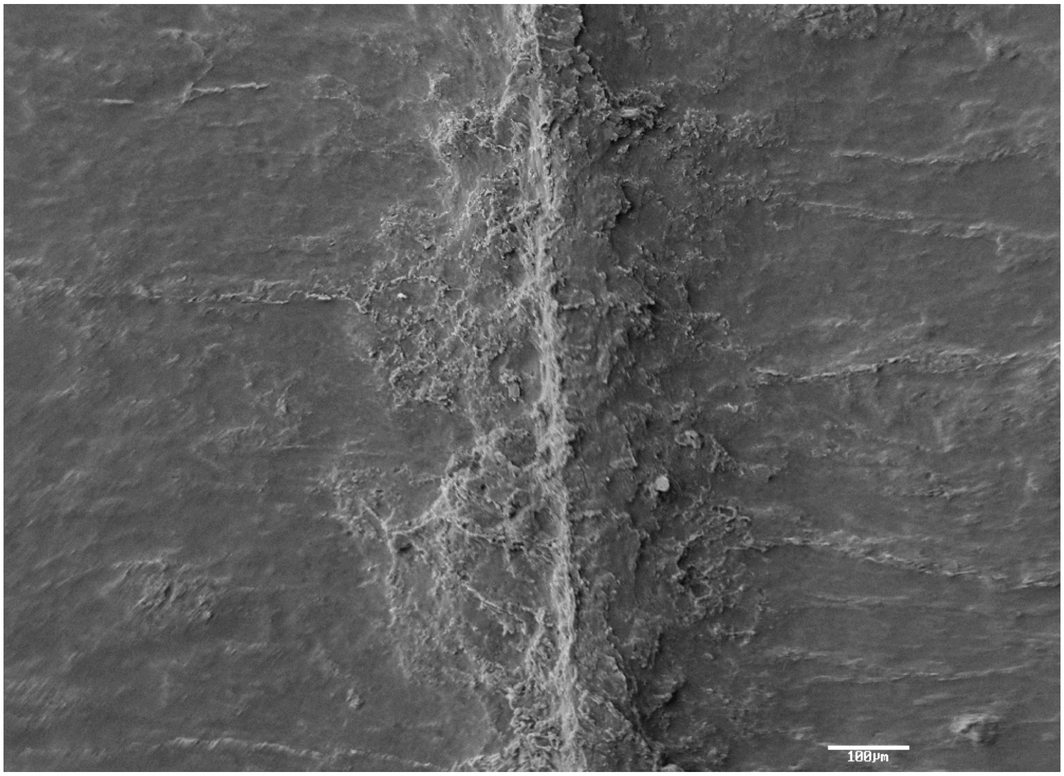

Figure 54. SEM image of Xantopren® mould of Cat#210 showing damaged cut mark with irregular kerf edges and partially intact apex (100x magnification).

An unforeseen difficulty proved to be the attachment of the Xantopren® moulds to stands for SEM preparation and examination. They resisted normal adhering methods and use of a hot glue gun was necessary. Figure C6 shows the appearance of a string of glue that was occasionally visible at the edges of moulds. Even with use of glue, the mountings were fragile and several moulds became damaged when they fell off their stands after gold coating.

Chapter 7

Discussion

7.1. SEM Study and Comparison with Experimental Cut Marks

One of the key objectives of the cut mark studies at Olduvai was to verify whether "not all bones altered by hominids will be found in association with stone tools" (Potts and Shipman 1981:579). Similarly, Walker and Long (1977:606) stated that "butchering marks may suggest the use of a specific class of tools at an archaeological site even though no such tools were recovered". For EfPm-27, this applies to the potential for metal trade tools to have been utilized for butchering even though no metal knives were found. This necessitated the application of indirect methods, such as cut mark analysis, to investigate their presence or absence.

Proof of metal cut mark presence in this case would require clearly unambiguous metal cut marks. No such proof was discovered and, therefore, this study provides no evidence for the presence of metal cut marks or the use of metal tools for butchery at EfPm-27. In light of this, I was unable to reject the null hypotheses, as stated in Chapter 1, that metal cut marks are not present at EfPm-27. In contrast, proof for the presence of stone tool cut marks was abundant with both the presence of stone tools and clearly identifiable stone tool cut marks.

Considering that only a sample of the cut marked assemblage was analyzed with the SEM as well as potential macroscopic and microscopic sources of error, it is possible that metal cut marks may still be present in the assemblage, but at a significantly lower frequency than previously anticipated. However, all of the cut marks from EfPm-27 that were analyzed using the SEM that could be identified as to material type, were identified as most likely originating from stone tools. This determination is upon analysis of the marks and comparison with experimental marks as well as published data (Table 1).

When SEM images of cut marks from EfPm-27 were compared with the experimental marks similarities became evident. Many of the cut marks at EfPm-27 seem to have been created using simple unmodified blades, probably expedient flake tools, rather than bifacial stone knives. These findings are consistent with the artifactual evidence of the presence of flakes, debitage and projectile points but very few stone tools other than projectile points (Wickam and Walde 2001:16).

Figures 55 and 56 reveal a common mark appearance at EfPm-27. These are relatively uncomplicated and straight cut marks that most closely resemble SEM images of experimental cut marks Set 1 (Figure B11-B13). Figures 39-43 more closely resemble marks made by Set 2 (Figure B14-B18), but with a more worn appearance. However, marks resembling those created with modified flakes are also present to a relatively limited extent (Figure 57, Figure 13).

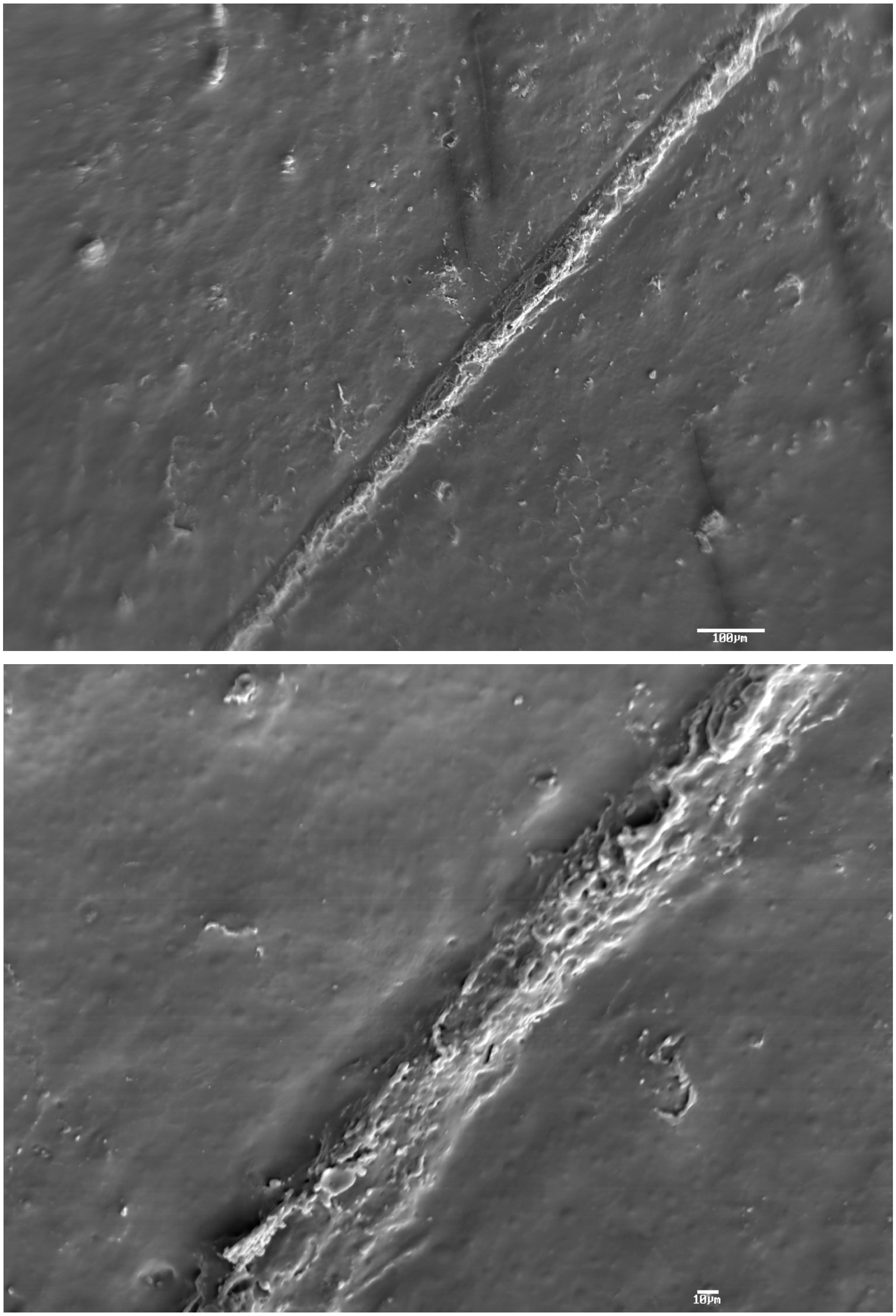

Figure 55. SEM images of Xantopren® mould of Cat#315: (top) stone cut mark (x100 magnification); (bottom) shows crumbled appearance of cut mark (x300 magnification).

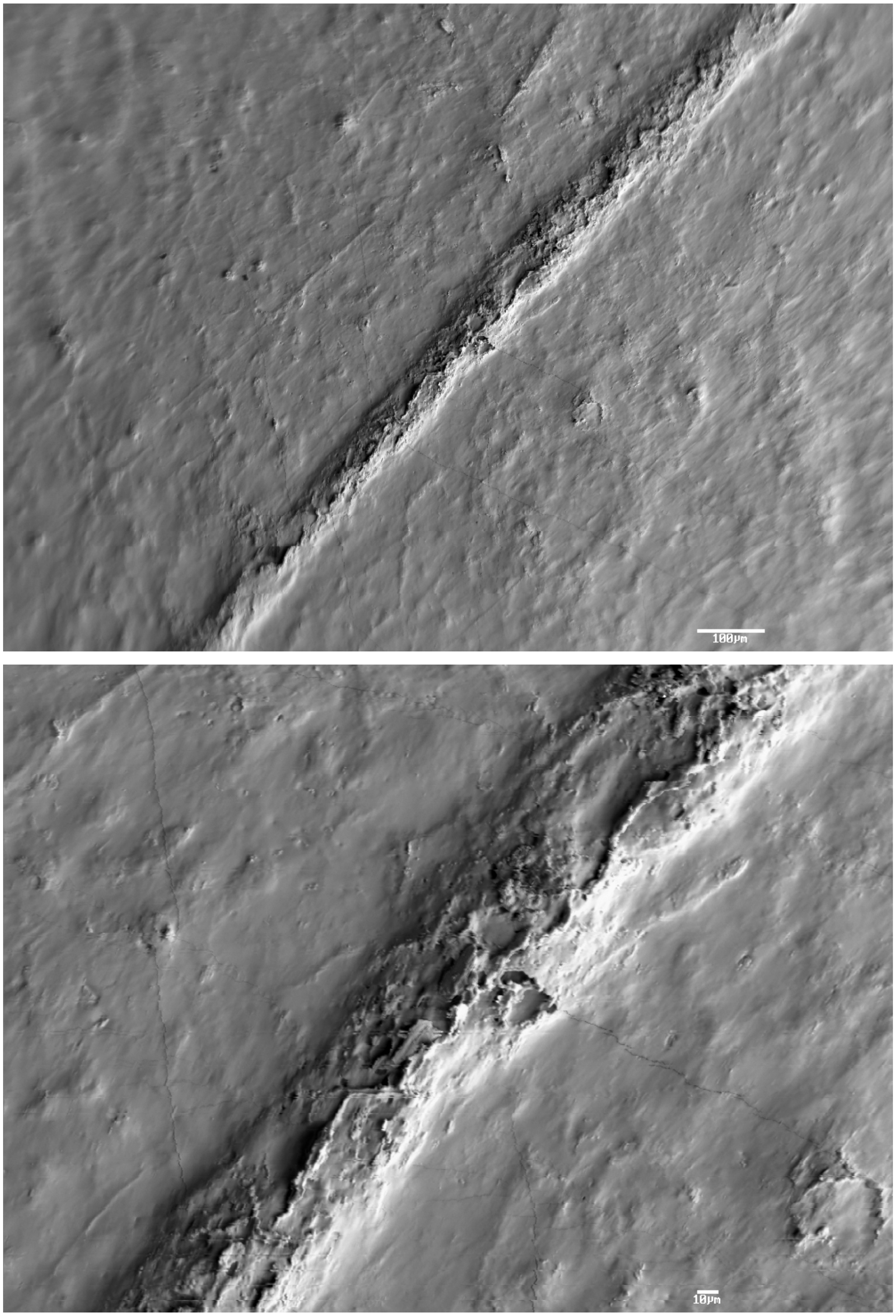

Figure 56. SEM images of Xantopren® mould of cut mark on Cat#309: (top) stone cut mark (x100 magnification); (bottom) shows crumbled appearance of cut mark (x300 magnification).

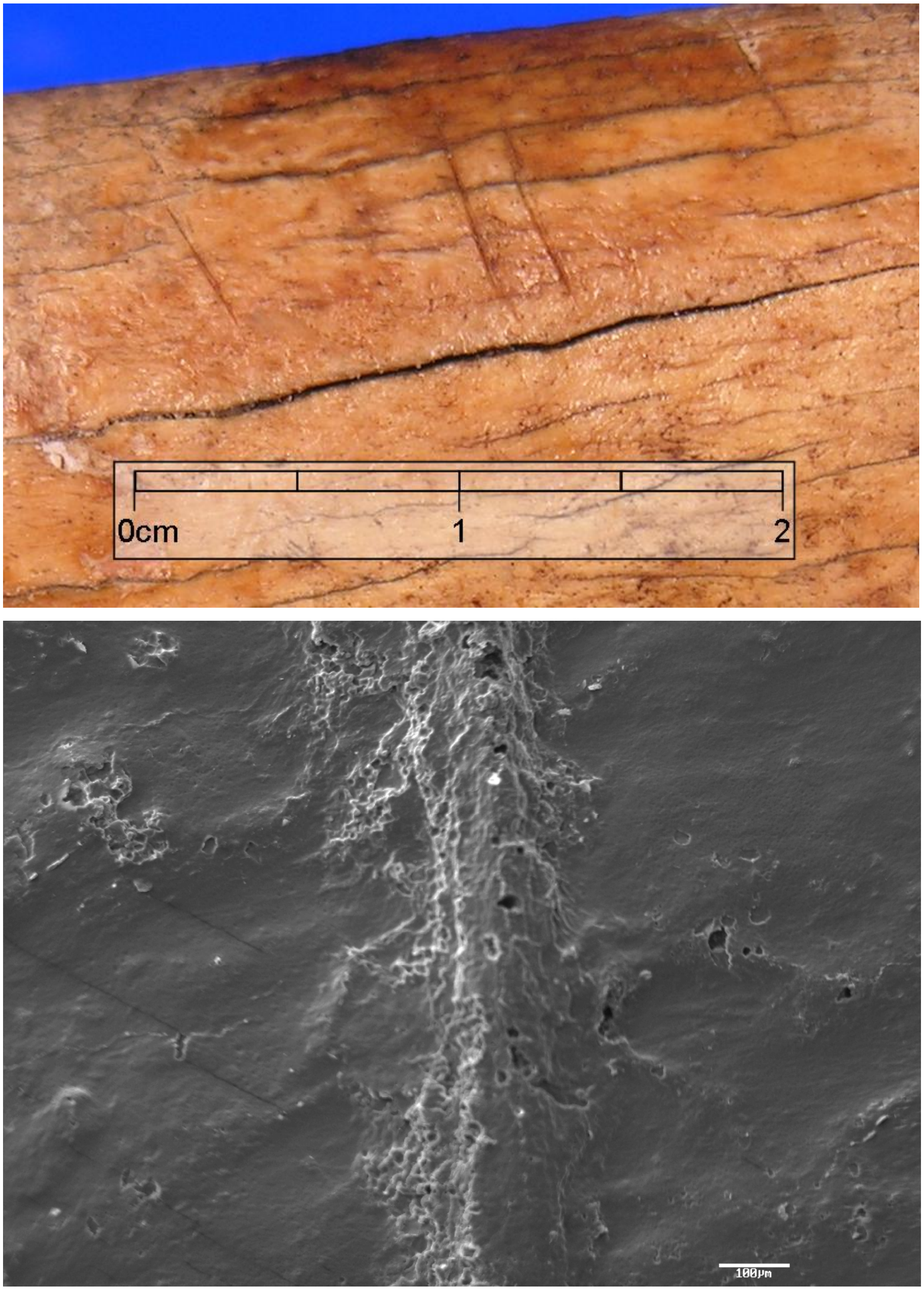

Figure 57. Two views of Cat#208: (top) detail macroscopic image of cut marks on ventral surface of dentary; (bottom) SEM image of Xantopren® mould of central cut mark (x100 magnification).

The similarities between EfPm-27 cut marks and experimental and published images of stone cut marks is in contrast to comparisons with historic and published metal cut marks images. The historic metal cut marks display distinct apexes, clean grooves, and are narrower and finer than the cut marks from EfPm-27. They exhibit a maximum width of less than 50μm, which is the minimum width of the finest cutmarks from EfPm-27.

7.2. Interpretations of Experimental Tools

Multiple tool types were employed in the creation of the experimental tool marks (Figure 28). A significant observation of the tools themselves included that the obsidian tools crumbled readily under pressure when in direct contact with bone, which caused small obsidian fragments to break off onto the bone surface and in the cut (Figures B2, B6, B8, and B11). In contrast, chert tools remained relatively intact, leaving few small fragments behind (Figures B4, B5, and B9).

The apparent discrepancy between the durability and effectiveness of obsidian and chert tools coincides with Walker and Long's (1977) research, which showed that there is a considerable difference in optimal pressure for different tool types and compositions. They found in their experiments, which employed steel knives, axes, and unmodified obsidian flakes to produce cut marks, that all of these tools produced "V-shaped grooves with a distinct apex at the bottom of the groove" (Walker and Long 1977:608). However, this similarity between the tool types is limited to very low applications of pressure because metal tools were comfortably applied at pressures that were three or more times greater than the optimal pressure for obsidian tools (Walker and Long 1977:611). At greater than optimal pressures, significant damage to the obsidian tools would ensue when cutting bone.

Walker and Long (1977:611) explained that "the depth of a tool mark is directly related to the amount of force applied", which was illustrated by their production of experimental obsidian tool marks of to a maximum depth of 0.21 mm compared to 0.41mm for a steel knife. Although no pressure or exact depth analysis was undertaken in the current study, there is a distinct indication of greater depth in Sets 2 and 3 (chert) when contrasted with Sets 1 and 4 (obsidian).

Similarly, Dewbury and Russell (2007:357) found that an individual utilizing obsidian flakes to butcher an animal would have to use less pressure compared to an individual using flint tools. This difference is due to the qualities of sharpness and durability, which vary inversely to each other. They (Dewbury and Russell 2007:357) suggested that this may result in a lower frequency of cut marks when employing a sharp yet fragile flake like obsidian vs. a higher cut mark frequency when using a duller tool. A duller tool would require more passes to cut the same amount as an obsidian flake, but would be better able to withstand greater applications of force without crumbling when contacting the bone surface.

These observations have relevance regarding what the potential tool types and materials most likely to have been employed for cutting meat near to the bone. One could infer that the incidence of tool breakage and shattering would reduce the appeal of using obsidian tools in scenarios where they would contact the bone. Not only does this contact damage the tool, but also it potentially contaminates the meat with obsidian fragments. Chert or some other durable yet fine stone material would be preferable in these instances. In addition, modified flakes and tools seem to be much more durable in this context than unmodified flakes. However, activities requiring very sharp and fine edges such as skinning, hide cutting, or possibly incidences where tendons must be cut would greatly benefit from the use of unmodified obsidian flakes.

7.3. Cut Mark Distribution at EfPm-27

Wickam (2005) gives a thorough examination of the butchering patterns evident at EfPm-27 taking into account fracture patterns and element presence/absence as well as cut mark distribution. The majority of this information is not included in the data set utilized for the current research. For a complete butchering pattern analysis, Wickam (2005) should be consulted. While cut marks provide important information regarding potential butchering processes, they are not sufficient for a complete butchering pattern analysis and, as such, the data contained herein are insufficient for that purpose.

Wickham (2005:116) made two clear assertions regarding the cut marked assemblage from EfPm-27: that there is a "clearly a regular pattern to the distribution and frequency of fine cut marks on the bones at EfPm-27" and that most of the fine cut marks reflect defleshing and disarticulation practices common during the Late Prehistoric period. These statements are corroborated by the present work using visual inspection of patterns. Figure 58 visually depicts the general cut mark distribution at EfPm-27 and Table 11 gives a brief summary of some of potential butchering activities associated with EfPm-27 cut mark locations of mapped cut marks.

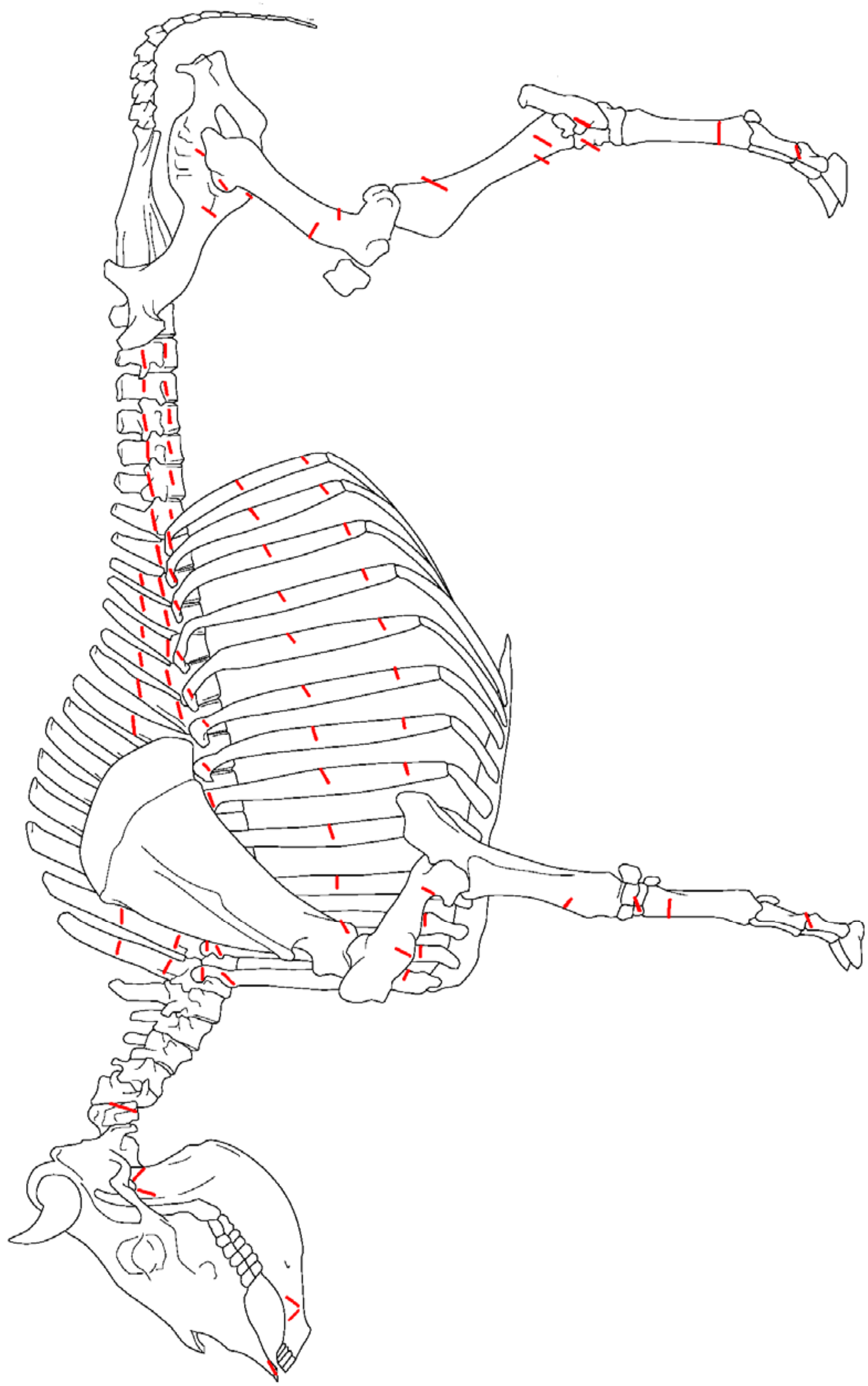

Figure 58. Generalized cut mark distribution at EfPm-27. Cut marks represented by fine red lines. See Figures A1, A4, A8 and A13 for cut marks not depicted in diagram. *Bison bison* diagram modified from Yvanic et al. (2003).

Table 11. Probable Activities Associated with Mapped Cut Marks at EfPm-27

Element	# of cut marks	Cut Mark Location	Probable Activity
Astragalus	6	Medial surface, caudal edge of medial surface	Disarticulation of the distal hindlimb
Atlas	2	Caudal articular surface	Disarticulation of cranium
Calcaneus	1	Medial articular surface	Disarticulation of the distal hindlimb
Cranium	1	Premaxilla	Skinning
Cranium	1	Palate	Tongue removal
Dentary	7	Medial surface of diastema	Tongue removal, dentary removal
Dentary	6	Medial surface of horizontal ramus	Tongue removal, dentary removal
Dentary	3	Lateral surface of diastema	Skinning
Dentary	2	Ascending ramus and coronoid process	Removal of dentary
Femur	2	Cranial surface, distal half of shaft	Defleshing
Femur	3	Medial surface distal half of shaft	Defleshing
Femur	1	Caudal surface distal half of shaft	Defleshing
Femur	1	Proximal end of shaft/neck	Defleshing or disarticulation
Femur	1	Head	Disarticulation
Humerus	1	Lateral surface, distal half of shaft	Defleshing
Humerus	1	Deltoid tuberosity	Defleshing
Hyoid	6	Medial surface	Tongue removal
Intermediate carpal	1	Exterior surface	Skinning or disarticulation
Lumbar	3	Transverse process	Defleshing
Lumbar	6	Base of spinous process	Defleshing
Lumbar	1	Centrum	Defleshing
Metapodial	7	Shaft	Skinning
Os coxa	3	Acetabular end of ilium shaft, lateral surface	Disarticulation
Os coxa	1	Acetabular end of ilium shaft, dorsal surface	Disarticulation
Os coxa	2	Acetabular end of ischium shaft, obturator foramen edge	Disarticulation
Os coxa	1	Acetabular end of shaft of pubis	Disarticulation
Os coxa	1	Sacral tuber of blade of ilium,	Disarticulation
Radius	3	Cranial surface, distal end shaft	Defleshing or disarticulation
Rib	3	Head and neck	Defleshing or disarticulation
Rib	18	Shaft	Defleshing
Scapula	1	Neck	Defleshing or disarticulation
Second phalanx	1	Proximal articular surface	Disarticulation
Thoracic	119	Spinous process	Defleshing
Tibia	4	Distal end shaft	Disarticulation
Tibia	1	Proximal end shaft caudal surface	Defleshing

Large mammal utilization processes typically include several overlapping phases: skinning, primary dismemberment, secondary processing (including further dismemberment, meat cut removal, filleting, etc.), and tertiary processing (including cooking or preservation of meat, marrow and bone grease extraction, etc.) (Binford 1981b:106). While these phases will often overlap or vary in their thoroughness, out of necessity they are typically sequential. The majority of the cut marks and identifiable butchering processes from EfPm-27 can be associated with the butchering processes of skinning and primary dismemberment and butchering.

Noe-Nygaard (1989:478) asserted that cut marks would result from skinning processes at locations where very little meat separate the hide from the bone. Braun et al. (2008:1222) noted that skinning often results in cut marks on the distal limbs including the "carpals, tarsals, and distal metapodia". Skinning activities at EfPm-27 are indicated by lateral cuts on the shafts of the lower long bones including the distal tibia (Cat#581, 583, 567, and 572), distal radius (Cat#520, 515, and 519), metapodials (Cat#588, 595, 602, 604, 605, 606, and 610), and phalanges (Cat#615). Binford (1981b:103) suggested that a preponderance of cuts on the metapodials and lower long bones suggests a primary concern for meat as opposed to hides. However, Binford's data were based upon reindeer butchering rather than *B.bison*.

Disarticulation and dismemberment cut marks are represented by marks near to joints, focussed on long bone ends (Braun et al. 2008:1222). These typically represent cutting actions through meat to expose the cartilaginous joint (Noe-Nygaard 1989:482). Noe-Nygaard (1989:482) noted that dismemberment marks are "often deep and distinct" but are relatively rare. At EfPm-27, disarticulation and dismemberment cut marks were inflicted on the os coxa and long bones including the scapula. Cuts on the glenoid and neck of the scapula may suggest disarticulation of the forelimb (Binford 1980b:121).

Cuts near the acetabulum on the os coxa may have resulted from action to “cut the transverse acetabular ligament which would allow exposure of the round ligament to the head of the femur by properly manipulating the femur” (Frison 1970:16). This would allow for easier removal of the hind limb at this joint. Binford (1981b:101) agreed with this when he stated, “marks encircling the acetabulum are presumably made during the cutting of the iliofemoral and ischiofemoral ligaments, which tend to encase the coxal articulation.” Such marks, being associated with the removal of the lower limb from the pelvis, are part of the primary butchering process of initial dismemberment (Binford 1981b:114).

Binford (1981b:101) noted that “marks on the mandible tend to be slightly oblique incised marks on the inside of the mandible generally opposite the M2 tooth. The marks are believed to originate from the underside of the mandible and to be related to the severing of the mylohyoid muscle during the removal of the tongue”. These same types of marks are noted by Frison (1970:11) at the Glenrock site. Also seen at EfPm-27 are cut marks on the hyoid bone, which are commonly associated with tongue removal. Binford (1981b:109) explained that the removal of the tongue, while not an act of dismemberment, is generally considered to be a primary butchering process event.

Cut marks associated with defleshing activities tend to occur along the shafts of long bones or on elements such as the ribs and vertebrae (Braun et al. 2008:1222). Cut marks on ribs and vertebrae are abundant at EfPm-27 (Table 11, Appendix A) although there are relatively few appearing on long bone shafts (Figure 66).

As discussed in section 4.4, cut mark frequency is a relatively ineffectual line of investigation unless significant idiosyncrasies exist. This study did not pursue cut mark frequency above recording and examining the assemblage for such idiosyncrasies. On cursory inspection (Table 11), a clear frequency variation emerges in that greater than 50% of the cut marks appear on thoracic vertebrae (despite thoracic vertebrae accounting for less than 20% of cut marked the assemblage). These marks are predominantly on one side of the vertebrae only.

Frison (1970:20) observed the common occurrence of prominent horizontal cut marks at the base of the spinous process on thoracic vertebrae from Glenrock Buffalo Jump (48CO304), but pointed out that this "usually appear[s] on both sides" (Frison 1970:20). In the Fish Creek assemblage, only 12 of the 121 mapped thoracic elements (approximately 9.9%) exhibit cut marks on both sides (Figure A18). Further, only 10 of the cut marked thoracic elements show an intact spinous process, 4 of which exhibit cut marks on both sides. Arguably, as a well-represented cut marked element in the Fish Creek assemblage this discrepancy is not attributable to lack of preservation. A potential butchering pattern at EfPm-27 might have included cutting through the hump meat to the spinous process on one side, breakage of the shaft of the spinous process and subsequent cutting through the hump meat on the other side on the spinous process.

7.4. Site Comparisons and Potential for Future SEM Research

One of the original objectives of the current research was to compare metal and stone tool cut mark distribution at EfPm-27 to cut marks at other Protohistoric sites. If metal cut marks had been identified and a difference in frequency or distribution had been discovered, this information could have been compared to cut mark distribution patterns at other Protohistoric sites to look for correlations. While this objective proved to be unachievable with EfPm-27, there remains the potential for the application of the information gained to comparisons and interpretations of selected Protohistoric sites.

Thorough information regarding Protohistoric butchering on the plains remains relatively limited. Wickam (2005:18) refered to several important Late Pre-contact/ Protohistoric sites within the vicinity of EfPm-27. However, much unpublished information describing other sites remains in the “grey literature” of consultant’s reports. Vivian et al. (2005b:Figure 49) noted four significant Protohistoric kill sites in the Calgary area that have been excavated. Besides EfPm-27 there are one kill (EhPn-45, the Grey Meadows site), one kill/camp (EgPn-430, the Crestmont site), and one kill/processing (EhPm-34, H.M.S. Balzac) site.

The Protohistoric kill/camp site of EgPn-430 was excavated and analyzed by Lifeways of Canada Ltd. (Vivian et al. 2005a, 2005b). The faunal analyses in the site reports describe butchering patterns at the site in depth. Vivian et al. (2005a:Figure 21) reported the cut mark distribution of EgPn-430 Area 3 and Vivian et al. (2005b:Figure 18) reported the cut mark distribution of EgPn-430 Area 6.

On cursory inspection, the distribution pattern at EfPm-27 resembles that at EgPn-430 Area 6 in the axial skeleton and femora, but EgPn-430 appears to have much higher concentration of cuts on the proximal and distal limb bones. While the distribution at EfPm-27 suggests a focus on disarticulation, EgPn-430 Area 6 reveals a greater degree on limb processing over and above hide removal and segmentation of the carcass. The other areas showed a similar overlap of the typical cuts on the ribs and thoracic vertebra but fewer cut marks identified on the appendicular skeleton than EfPm-27.

Vivian et al. (2005b:39) made the tentative assertion that metal cut marks may be assumed to be present at EgPn-430 Area 6 since both stone and metal tools were discovered at the location:

> "Further investigation of the butchery marks at EgPn-430 Area Six with the use of a scanning electron microscope could be useful in identifying another aspect of analysis. However, suffice it to say that if the tool system used at the site included both stone and metal implements (as evidenced by projectile points), it is likely that both stone and metal implements were used during butchering (the metal knife blade found on the western periphery of site would support this conclusion)." [Vivian et al. 2005b:40]

I would agree with the recommendation that the site should be analyzed using the SEM. As EfPm-27 has shown, the assumption that metal tools are being employed for butchering at Protohistoric sites based solely on the presence of metal tools cannot be supported. However, EgPn-430 Area 6 recovered significantly more metal trade tools than were recovered at EfPm-27 (Vivian et al. 2005b:14-23). These included 11 copper and 7 iron projectile points, 1 iron knife, 1 iron file, and several other items (1 iron clasp, 1 brass button, 1 glass bead) which dated the site to approximately 1800 (Vivian 2005b:66). The probable site date and the presence of an iron knife are indicators that the site would have been in the direct European trade route, enabling an increased utilization of trade metal. However, the presence of such tools is indirect evidence for metal tool butchery. It requires the direct evidence from identifiable metal cut marks to validate that the tools were employed in butchering.

Macroscopically, the reported examples of cut marks from the site appear quite wide, shallow, and robust as opposed to marks that resemble those depicted in Figure 14. Although, the report image of Cat#26669, a specimen described as having “chatter marks” (Vivian et al. 2005b:Plate A-17), may resemble the features of a saw mark (Figure 8) considering the exposed surface morphology and the expanse of bone that was cut. However, I would be hesitant to make this assertion without seeing images that are more conclusive.

Lensen’s (1995) investigation of butchering practices at Protohistoric sites from the Oldman River Dam Reservoir provided a very thorough cut mark analysis. Her methodology included identification of three major cultural mark types including “fine cutmarks”, “fine-scraping marks”, “heavy marks”, and “hack marks” (Lensen 1995:47). Data recorded about each mark included: the number of related cut marks, length, completeness, barb presence, relationship to any breaks (“unassociated”, “near”, or “caused”), and orientation.

Although four sites were examined (DjPm-126, DjPm-80, DjPm-100 and DjPm-115), DjPm-115 contained 97% of the observed cut marks (Lensen 1995:101) so only this site will be discussed herein. Lensen (1995:101) reported that the site contained a cut mark frequency of 5%, however, only 221 of these occur on identifiables. This suggests that 2.7% of the identifiable assemblage exhibited cut marks, which is only slightly higher than the 2.4% found at EfPm-27 in the current study (as mentioned in section 4.4). As in EfPm-27, the majority of these cut marks occur on the ribs and the thoracic vertebrae. However, as the site was a camp, there is evidence of secondary processing and defleshing cut marks coupled with poor representation of lower limb bones that is not evident at EfPm-27. Any cut mark distribution differences are likely be predominantly associated with the difference in site function and activity.

In terms of the potential for the application of the SEM, Lensen (1995:160) asserted that one of the mandibles at the site had been “severed with a metal axe or cleaver”. If metal tools such as this were being employed at the site, then it is probable that metal cut marks may also be present at the site. This makes DjPm-115 an excellent candidate for future examinations for a potential intra-site comparison of metal and stone tool butchering patterns.

Chapter 8

Conclusion

This research was undertaken with the express purpose of identifying the presence and extent of metal and stone tool cut marks at EfPm-27. To this end, a comparative collection of experimental tool marks was created to aid in identification. These, as well as historic metal cut marks and selected cut marked specimens from EfPm-27 were examined with the SEM by employing negative moulds of the cut marks. This also led to a comparison of the usefulness of several moulding compounds concluding that Xantopren® Comfort Light, C-silicone (condensation silicone) impression material was ideal for the purpose.

The EfPm-27 cut marks to be examined with the SEM were selected using an adaptive sampling strategy. A configurational approach was employed during macroscopic examination of the collection in order to separate the majority of pseudo-cut marks from true cut marks. Using the SEM, cut marks were inspected for known features of stone and metal tools and compared to experimental and historic comparative marks. All of the identifiable EfPm-27 cut marks examined with the SEM were found to resemble most closely the appearance of experimental and archaeological cut marks known to have been created by stone tools.

Shipman (1981b) points out that taphonomists "must ask of each assemblage how badly it misrepresents the original collection of bones or species" (Shipman 1981b:357). With this in mind, there is the possibility that metal cut marks may remain unidentified in the assemblage for several reasons. It is possible that metal tools were used for butchery but failed to leave any cut marks during the butchering process. In addition, metal tools or metal cut marks may have existed, but failed to deposit or preserve in the archaeological record or failed to be recovered, identified, and examined.

It is likely that at least some of the cut marks that were created during butchery were eradicated by the same taphonomic processes that resulted in a proportion of the preserved potential cut mark specimens to be inconclusive, damaged, or too fragile to be moulded for examination with the SEM. This, and time and budget constraints, meant that less than 100% of the cut marked assemblage could be examined using the SEM. While I am confident that the analyzed sample of the faunal assemblage was representative of the collection and the selection of specimens to be moulded was targeted towards discovery of metal cut marks, there remains the potential that metal cut marks could exist among the unexamined portion.

Similarly, 100% of the site has not been excavated and therefore metal cut marks or metal knives may yet be present in the unexcavated portions of the site. It is also possible that metal knives were present at one time but were not preserved in the archaeological record. Considering the condition of the recovered metal artifacts, this could be the result of poor preservation, but it could be related to the tendency to curate metal tools.

Conservation of metal tools is generally the rule and this is especially true in scenarios where metal is only available as scarce trade items. Even though trade metal fragments were discovered at EfPm-27, in all likelihood trade metal was scarce, highly curated, and potentially fragmentary or of low quality during the time of the site's occupation. Such metal fragments were probably reserved for use as projectile points or other small items like decorations, rather than knives. Compared to metal tools, stone tools have a shorter use life, but they have fewer material, labour, and technological requirements for their production (Greenfield 1999:798), making for a more disposable tool material. For these reasons, I would posit that early Protohistoric sites might tend to follow what is visible at EfPm-27, and have a predominance of stone and lack of metal cut marks until metal trade knives became more common. However, this has yet to be investigated and requires the application of SEM to cut marks in a greater sample of Protohistoric sites.

Butchering activities are based on cultural preferences, site type, and practical concerns regarding the technology available and physiology of the animal being butchered. One might question whether the acquisition of metal trade knives would be a great enough technological innovation to fuel a shift from traditional knife-based butchering practices. In addition, there is the potential for the active retention of traditional tools, at least for some activities (Hogue 2006:247), even if new technologies are available. Arguably, there would be little variation in the butchering pattern until European trade and contact intensified. Such contact would have brought significant cultural pressures and technological shifts that were not present during the Protohistoric. In particular, the introduction of metal saws, which have an entirely different functionality than metal or stone knives, would undoubtedly alter the butchering pattern.

Contrasting intra- and inter-site metal and stone tool butchery at Protohistoric sites, could potentially answer these questions. However, this is predicated on the discovery of a site containing both of the necessary cut mark types. If EfPm-27 is any indicator, this might be a difficult task. Potentially, the cut marks on bones from EgPn-430 or from DjPm-115 might provide an avenue for future SEM research in this area.

Cut marks are often used as a line of evidence for butchering processes in faunal analyses. However, a perennial difficulty is the mass of information that must be conveyed in a comprehensive faunal analysis. This tends to exclude taking the time and effort necessary to make a thorough study of the cut marks and pseudo-cut marks of a given site. Many such studies may utilize cut marks as part of a butchering analysis, but may not provide information as to specific characteristics of the marks, descriptions of them, or the rationale behind their identifications. These data would make findings more comparable and easier to verify and replicate.

Archaeologists should be aware of the limitations of individual physical features when analyzing damage morphology and employ a configurational approach to maximize the supporting evidence for identifications. Multiple studies and personal experience appear to concur that, on a relatively uncompromised bone surface, major forms of tool marks and pseudo-tool marks can be adequately identified as to probable source using a configurational approach and macroscopic examination. However, in ambiguous cases, such as those involving damaged marks, mark overlap, or when the origin of the tool mark is anything but obvious based on both context and morphology, then the degree of confidence of a naked eye inspection is significantly lowered.

The present study reinforces the fact that stone tool cut marks can be macroscopically deceptive, especially in scenarios where contextual information is inconclusive. It is evident that the taphonomic equifinality of cut marks of different material types can be subject to the degree of magnification under which they are examined. While compromised marks may be beyond classification, the application of SEM to the identification of the material source of uncompromised slicing cut marks is necessary.

While it is unrealistic to expect complete SEM analyses at all Protohistoric sites, potentially a representative sample of cut marks could be analyzed using the SEM to check for the presence or absence of multiple material types. Failing the adequate funding, time, or expertise for such endeavours, it is necessary that archaeologists be hesitant to identify cut marks as derived from metal or stone tools unless probable tool composition, based on multiple lines of evidence, is clear.

References Cited

Abe, Y., C.W. Marean, P.J. Nilssen, Z. Assefa, and E.C. Stone
2002 The Analysis of Cutmarks on Archaeofauna: A Review and Critique of Quantification Procedures, and a New Image-Analysis GIS Approach. *American Antiquity* 67 (4):643-663.

Alhaique, F., M. Bisconti, E. Castiglioni, C. Cilli, L. Fasani, G. Giacobini, R. Grifoni, A. Guerreschi, A. Iacopini, G. Malerba, C. Peretto, A. Recchi, A.R. Ris, A. Ronchitelli, M. Rottoli, U.T. Hohenstein, C. Tozzi, P. Visentini, and B. Wilkens
2004 Animal Resources and Subsistence Strategies. *Collegium Antropologicum* 28(1):23–40.

Alunni-Perret, V., M. Muller-Bolla, J.P. Laugier, L. Lupi-Pegurier, M.F. Bertrand, P. Staccini, M. Bolla and G.R. Quatrehomme
2005 Scanning Electron Microscopy Analysis of Experimental Bone Hacking Trauma. *Journal of Forensic Sciences* 50:796-801.

Andrews, P.
1995 Experiments in Taphonomy. *Journal of Archaeological Science* 22:147-153.

Andrews, P. and M. Armour-Chelu
1998 Taphonomic Observations on a Surface Bone Assemblage in a Temperate Environment. *Bulletin de la Société Géologique de France* 169(3):433-442.

Andrews, P. and J. Cook
1985 Natural Modifications to Bones in a Temperate Setting. *Man* 20:675-691.

Andrews, P. and Y. Fernández-Jalvo
1997 Surface Modifications of the Sima de los Huesos Fossil Humans. *Journal of Human Evolution* 33:191-217.

Armour-Chelu, M., and P. Andrews
1996 Surface Modifications on Bone. In *The Experimental Earthworks Project 1960–1992*, edited by M. Bell, pp. 178-185. Council for British Archaeology, York.

Bartelink, E.J., J.M. Wiersema, and R.S. Demaree,
2001 Quantitative Analysis in Sharp Force Trauma: An Application of Scanning Electron Microscopy in Forensic Anthropology. *Journal of Forensic Sciences* 46(6):1288-1293.

Behrensmeyer, A.K.
1978 Taphonomic and Ecologic Information from Bone Weathering. *Paleobiology* 4:150-163.

Behrensmeyer, A.K. and D.E. Boaz
1980 The Recent Bones of Amboseli National Park, Kenya. In *Fossils in the Making: Vertebrate Taphonomy and Paleoecology*, edited by A.K. Behrensmeyer and A.P. Hill, pp. 72-92. University of Chicago Press, Chicago.

Behrensmeyer, A.K., K.D. Gordon, and G.T. Yanagi
1986 Trampling as a Cause of Bone Surface Damage and Pseudo-Cut Marks. *Nature* 319:768-771.

1989 Non-Human Modification in Miocene Fossils from Pakistan. In *Bone Modification*, edited by R. Bonnichsen and M. Sorg, pp. 99-120. Centre for the Study of the First Americans, University of Maine, Orono.

Behrensmeyer, A.K., C.T. Stayton, and R.E. Chapman
2003 Taphonomy and Ecology of Modern Avifaunal Remains from Amboseli Park, Kenya. *Paleobiology* 29(1):52-70.

Berryman, H.E.
2002 Disarticulation Pattern and Tooth Mark Artifacts Associated with Pig Scavenging of Human Remains: A Case Study. In *Advances in Forensic Taphonomy: Method, Theory, and Archaeological Perspectives* edited by W.D. Haglund and M. Sorg, pp. 487-495. CRC Press, Boca Raton, Florida.

Biasotti, A., and J. Murdock
1984 Criteria for Identification in Firearms and Toolmark Identification. *AFTE Journal* 16(4):16-24.

Biddick, K.A. and J. Tomenchuck
1975 Quantifying Continuous Lesions and Fractures on Long Bones. *Journal of Field Archaeology* 2:239-249.

Binford, L.R.
1978 *Nunamiut Ethnoarchaeology*. Academic Press, New York.

1981a Behavioural Archaeology and the "Pompeii Premise". *Journal of Anthropological Research* 37(3):195-208.

1981b *Bones: Ancient Men and Modern Myths*. Academy Press, New York.

1984 *Faunal Remains from the Klasies River Mouth*. Academic Press, New York.

Blumenschine, R.J.
1988 An Experimental Model of the Timing of Hominid and Carnivore Influence on Archaeological Bone Assemblages. *Journal of Archaeological Science* 15:483-502.

1995 Percussion Marks, Tooth Marks, and Experimental Determinations of the Timing of Hominid and Carnivore Access to Long Bones at FLK Zinjanthropus, Olduvai Gorge, Tanzania. *Journal of Human Evolution* 29:21-51.

Blumenschine, R. J. and C.W. Marean
1993 A Carnivore's View of Archaeological Bone Assemblages. In *From Bones to Behaviour*, edited by J. Hudson, pp. 273-300. Center for Archaeological Investigations, Southern Illinois University, Carbondale.

Blumenschine, R.J., C.W. Marean, and S.D. Capaldo
1996 Blind Tests of Inter-Analyst Correspondence and Accuracy in the Identification of Cut Marks, Percussion Marks, and Carnivore Tooth Marks on Bone Surfaces. *Journal of Archaeological Science* 23:493-507.

Blumenschine, R.J., K.A. Prassack, C.D. Kreger, and M.C. Pante
2007 Carnivore Tooth-Marks, Microbial Bioerosion, and the Invalidation of Domínguez-Rodrigo and Barba's (2006) Test of Oldowan Hominin Scavenging Behaviour. *Journal of Human Evolution* 53:420-426

Blumenshine, R.J. and M.M. Selvaggio
1988 Percussion Marks on Bone Surfaces as a New Diagnostic of Hominid Behaviour. *Nature* 333:763-765.

1991 On the Marks of Marrow Bone Processing by Hammerstones and Hyaenas: Their Anatomical Patterning and Archaeological Implications. In *Cultural Beginnings*, edited by J.D. Clark, pp. 17-32. Dr. Rudolf Habelt GMBH, Bonn, Germany.

Bonnichsen, R.
1973 Some Operational Aspects of Human and Animal Bone Alteration. In *Mammalian Osteo-archaeology: North America* edited by B.M. Gilbert, pp. 9-25. Missouri Archaeological Society, Columbia, Missouri.

Bonnichsen, R. and M. Sorg (editors)
1989 *Bone Modification*. Centre for the Study of the First Americans, University of Maine, Orono.

Bonnichsen, R. and R.T. Will
1990 Cultural Modification of Bone: The Experimental Approach in Faunal Analysis. In *Mammalian Osteology*, edited by B.M. Gilbert, pp. 7-30. Missouri Archaeological Society, Columbia.

Bonte, W.
1975 Tool Marks in Bone and Cartilage. *Journal of Forensic Sciences* 20(2):315-325.

Brain, C.J.
1976 Bone Weathering and the Problem of Bone Pseudo-Tools. *South African Journal of Science* 63:97-99.

1981 *The Hunters or The Hunted? An Introduction to African Cave Taphonomy*. University of Chicago Press, Chicago.

Braun, D.R., B.L. Pobiner, J.C. Thompson
2008 An Experimental Investigation of Cut Mark Production and Stone Tool Attrition. *Journal of Archaeological Science* 35(5):1216-1223.

Bromage, T.G.
1984 Interpretation of Scanning Electron Microscopic Images of Abraded Forming Bone Surfaces. *American Journal of Physical Anthropology* 64:161-178.

1987 The Scanning Electron Microscopy/Replica Technique and Recent Applications to the Study of Fossil Bone. *Scanning Microscopy* 1:607-613.

Bromage, T.G. and A. Boyde
1984 Microscopic Criteria for the Determination of Directionality of Cut Marks on Bone. *American Journal of Physical Anthropology* 65:359-366.

Brothwell, D.
1972 The Study of Archaeological Materials by Means of the Scanning Electron Microscope: An Important New Field. In *Science in Archaeology: A Survey of Progress and Research*, edited by D. Brothwell and E. Higgs, pp. 564-565. Thames and Hudson, London.

1976 Further Evidence of Bone Chewing by Ungulates: The Sheep of North Ronaldsay. *Journal of Archaeological Science* 3(2):179-182.

Bueschgen, W.D. and D.T. Case
1996 Evidence of Prehistoric Scalping at Vosberg, Central Arizona. *International Journal of Osteoarchaeology* 6:230-248.

Bunn, H.T.
1981 Archaeological Evidence for Meat-Eating by Plio-Pleistocene Hominids from Koobi Fora and Olduvai Gorge. *Nature* 291:574-577.

1989 Diagnosing Plio-Pleistocene Hominid Activity with Bone Fracture Evidence. In *Bone Modification*, edited by R. Bonnichsen and M. Sorg, pp. 299-315. Centre for the Study of the First Americans, University of Maine, Orono.

1991 A Taphonomic Perspective on the Archaeology of Human Origins. *Annual Review of Anthropology* 20:433-467.

2001 Hunting, Power-Scavenging, and Butchering by Hadza Foragers and by Plio-Pleistocene *Homo*. In *Meat-Eating and Human Evolution*, edited by C.B. Stanford and H.T. Bunn, pp. 199-218. Oxford University Press, Oxford.

Bunn, H.T. and R.J. Blumenschine
1987 On "Theoretical Framework and Tests" of Early Hominid Meat and Marrow Acquisition: A Reply to Shipman. *American Anthropologist* 89:444-448.

Bunn, H.T. and E.M. Kroll
1986 Systematic Butchery by Plio-Pleistocene Hominids at Olduvai Gorge, Tanzania. *Current Anthropology* 27:431-452.

Capaldo, S.D.
1997 Experimental Determinations of Carcass Processing by Plio-Pleistocene Hominids and Carnivores at FLK 22 (Zinjanthropus), Olduvai Gorge, Tanzania. *Journal of Human Evolution* 33:555-597.

Choi, K. and D. Driwantoro
2007 Shell Tool Use by Early Members of *Homo erectus* in Sangiran, Central Java, Indonesia: Cut Mark Evidence. *Journal of Archaeological Science* 34:48-58.

Clark, G.A. and N.R. Coinman
2003 The Paleolithic in Syria-Palestine. In *Near Eastern Archaeology: A Reader*, edited by S. Richard, pp. 233-243. Eisenbraus, Winona Lake, Indiana.

Cook, J.
1986 The Application of Scanning Electron Microscopy to Taphonomic and Archaeological Problems. In *Studies in the Upper Paleolithic of Britain and Northwest Europe*, edited by D.A. Roe, pp. 143-163. BAR International Series 296. British Archaeological Reports, Oxford.

Crowe-Swords, D.B. and M.G. Hanna
1980 *EfPm-27: Report on the 1979 Excavations*. Report on file, Archaeological Survey of Alberta, Edmonton.

Cruz-Uribe, K. and R.G. Klein
1994 Chew Marks and Cut Marks on Animal Bones from the Kasteelberg B and Dune Field Midden Later Stone Age Sites, Western Cape Province, South Africa. *Journal of Archaeological Science* 21:35-49.

Denys, C.
2002 Taphonomy and Experimentation. *Archaeometry* 44(3):469-484.

Denys, C., P. Andrews, Y. Dauphin, T. Williams, and Y. Fernández-Jalvo
1997 Towards a Site Classification: Comparison of the Diversity of Taphonomic and Diagenetic Patterns and Processes. *Bulletin de la Société Geologique de France* 168(6):751–757.

Dewbury, A.G. and Y.N. Russell
2007 Relative Frequency of Butchering Cutmarks Produced by Obsidian and Flint: an Experimental Approach. *Journal of Archaeological Science* 34:354-357.

Domínguez-Rodrigo, M.
1997 Meat-Eating by Early Hominids at the FLK 22 Zinjanthropus Site, Olduvai Gorge (Tanzania): An Experimental Approach Using Cut-Mark Data. *Journal of Human Evolution* 33:669-690.

1999 Distinguishing Between Apples and Oranges: The Application of Modern Cut-Mark Studies to the Plio-Pleistocene (A Reply to Monahan). *Journal of Human Evolution* 37:793-800.

2008 Conceptual Premises in Experimental Design and their Bearing on the Use of Analogy: An Example from Experiments on Cut Marks. *World Prehistory* 40:67-82.

Domínguez-Rodrigo, M. and R. Barba
2006 New Estimates of Tooth Mark and Percussion Mark Frequencies at the FLK Zinj Site: The Carnivore-Hominid-Carnivore Hypothesis Falsified. *Journal of Human Evolution* 50:170-194.

Domínguez-Rodrigo, M., C.P. Egeland, and R. Barba
2007 The "Physical Attribute" Taphonomic Approach. In *Deconstructing Olduvai: A Taphonomic Study of the Bed I Sites*, edited by M. Domínguez-Rodrigo, R. Barba, and C.P. Egeland, pp. 23-32. Springer, Dordrecht, Netherlands.

Domínguez-Rodrigo, M., T.R. Pickering, S. Semaw, and M.J. Rogers
2005 Cutmarked Bones from Pliocene Archaeological Sites at Gona, Afar, Ethiopia: Implications for the Function of the World's Oldest Stone Tools. *Journal of Human Evolution* 48:109-121.

Domínguez-Rodrigo, M. and A. Piqueras
2003 The Use of Tooth Pits to Identify Carnivore Taxa in Tooth-Marked Archaeofaunas and their Relevance to Reconstructing Hominid Carcass Processing Behaviours. *Journal of Archaeological Science* 30(11):1385-1391.

Domínguez-Rodrigo, M. and J. Yravedra
2009 Why Are Cut Mark Frequencies in Archaeofaunal Assemblages So Variable? A Multivariate Analysis. *Journal of Archaeological Science* 36:884–894.

Du Pasquier, E., J. Hebrard, P. Margot, and M. Ineichen
1996 Evaluation and Comparison of Casting Materials in Forensic Sciences: Applications to Tool Marks and Foot/Shoe Impressions. *Forensic Science International* 82 (1996) 33-43.

During, E.M. and L. Nilsson
1991 Mechanical Surface Analysis of Bone: A Case Study of Cut Marks and Enamel Hypoplasia on a Neolithic Cranium from Sweden. *American Journal of Physical Anthropology* 84:113-125.

Edgar, H.J.H. and P.W. Sciulli
2006 Comparative Human and Deer (*Odocoileus virginianus*) Taphonomy at the Richards Site, Ohio. *International Journal of Osteoarchaeology* 16:124-137.

Efremov, I.A.
1940 Taphonomy: A New Branch of Paleontology. *Pan-American Geologist* 74:81-93.

Egeland, C.P.
2003 Carcass Processing Intensity and Cutmark Creation: An Experimental Approach. *Plains Anthropologist* 48(184):39-51.

Eickhoff, S. and B. Hermann
1985 Surface Marks on Bones from a Neolithic Collective Grave (Odagsen, Lower Saxony): A Study on Differential Diagnosis. *Journal of Human Evolution* 14:263-274.

Fejfar, O. and T.M. Kaiser
2005 Insect Bone-Modification and Paleoecology of Oligocene Mammal-Bearing Sites in the Doupov Mountains, Northwestern Bohemia. *Palaeontologia Electronica* 8:1-11. Electronic document, http://palaeo-electronica.org/2005_1/fejfar8/issue1_05.htm, accessed September 2008.

Fernández-Jalvo, Y. and P. Andrews
1992 Small Mammal Taphonomy of Gran Dolina, Atapuerca (Burgos), Spain. *Journal of Archaeological Science* 19:407-428.

Fernández-Jalvo, Y., P. Andrews, and C. Denys
1999 Cut Marks on Small Mammals at Olduvai Gorge Bed-I. *Journal of Human Evolution* 36:587-589.

Fernández-Jalvo, Y. and M.D.M. Monfort
2008 Experimental Taphonomy in Museums: Preparation Protocols for Skeletons and Fossil Vertebrates Under the Scanning Electron Microscopy. *Geobios* 41:157–181.

Fiorillo, A.R.
1989 An Experimental Study of Trampling: Implications for the Fossil Record. In *Bone Modification*, edited by R. Bonnichsen and M. Sorg, pp. 61-71. Centre for the Study of the First Americans, University of Maine, Orono.

Fisher, J.W.
1995 Bone Surface Modifications in Zooarchaeology. *Journal of Archaeological Method and Theory* 2(1):7-68.

Frayer, D.W. and J.G. Bridgens
1985 Stab Wounds and Personal Identity Determined from Skeletal Remains: A Case from Kansas. *Journal of Forensic Sciences* 30(1):232-238.

Frison, G.
1970 The Glenrock Buffalo Jump, 48CO304: Late Prehistoric Period Buffalo Procurement and Butchering on the Northwest Plains. *Plains Anthropologist*, Memoir 7, 15(50 Pt.2):1-66.

Gautier, A.
1993 Trace Fossils in Archaeozoology. *Journal of Archaeological Science* 20:511-523.

Gibert, J. and C. Jimenez
1991 Investigations into Cut-Marks on Fossil Bones of Lower Pleistocene Age from Venta Micena (Orce, Granada Province, Spain). *Human Evolution* 6:117-128.

Gilbert, B.M.
1969 Some Aspects of Diet and Butchering Techniques Among Prehistoric Indians in South Dakota. *Plains Anthropologist* 14:277-294.

Gilbert, A.S. and B.H. Singer
1982 Reassessing Zooarchaeological Quantification. *World Archaeology* 14(1):21-40.

Gifford, D.P.
1980 Ethnoarchaeological Contributions to the Taphonomy of Human Sites. In *Fossils in the Making*, edited by A.K. Behrensmeyer and A.P.Hill, pp. 93-106. University of Chicago Press, Chicago.

Gifford-Gonzalez, D.
1991 Bones Are Not Enough: Analogues, Knowledge, and Interpretive Strategies in Zooarchaeology. *Journal of Anthropological Archaeology* 10:215–254.

Government of Alberta
2008 *Fish Creek Provincial Park*. Electronic document, http://tpr.alberta.ca/parks/fishcreek/history.asp, accessed February 23, 2009.

Greenfield, H.J.
1999 The Origins of Metallurgy: Distinguishing Stone from Metal Cut Marks on Bones from Archaeological Sites. *Journal of Archaeological Science* 26:797-808.

2000 The Origins of Metallurgy in the Central Balkans Based on the Analysis of Cut Marks on Animal Bones. *Environmental Archaeology* 5:119-132.

2002 Distinguishing Metal (Steel and Low-Tin Bronze) from Stone (Flint and Obsidian) Tool Cut Marks on Bone: An Experimental Approach. In *Experimental Archaeology: Replicating Past Objects, Behaviors, and Processes*, edited by J.Mathieu, pg.35-54. BAR International Series 1035. British Archaeological Reports, Oxford.

2006 Slicing Cut Marks on Animal Bones: Diagnostics for Identifying Stone Tool Type and Raw Material. *Journal of Field Archaeology* 31:147-163.

Gruspier, K.L.
1999 Pathological Changes on Human Skeletal Remains: Before, During, or After? In *Forensic Osteological Analysis: A Book of Case Studies*, edited by S.I. Fairgrieve, pp. 199-225. Charles C. Thomas, Springfield, Illinois.

Guilday, J.E., P.W. Parmalee, and D.P. Tanner.
1962 Aboriginal butchering techniques at the Eschelman site (36LA12), Lancaster County, Pennsylvania. *Pennsylvania Archaeologist* 32:59-83.

Haglund, W.D.
1992 Rodents and Human Remains. *Journal of Forensic Sciences* 37:1459-1465.

1997 Dogs and Coyotes: Postmortem Involvement with Human Remains. In *Forensic Taphonomy: The Postmortem Fate of Human Remains*, edited by W.D. Haglund and M.H. Sorg, pp. 367-381. CRC Press, Boca Raton, Florida.

Haglund, W.D., D.T. Reay and D.R. Swindler
1988 Tooth Mark Artifacts and Survival of Bones in Animal Scavenged Human Skeletons. *Journal of Forensic Sciences* 33:985-997.

1992 Contribution of Rodents to Postmortem Artifacts of Bone and Soft Tissue. *Journal of Forensic Sciences* 37(6):1459-1465.

Haglund, W.D. and M.H. Sorg (editors)
1997 *Forensic Taphonomy: The Postmortem Fate of Human Remains*. CRC Press, Boca Raton, Florida.

2002 *Advances in Forensic Taphonomy*. CRC Press, Boca Raton, Florida.

Haynes, G.
1980 Evidence of Carnivore Gnawing on Pleistocene and Recent Mammalian Bones. *Paleobiology* 6:341-351.

1983 A Guide for Differentiating Mammalian Carnivore Taxa Responsible for Gnaw Damage to Herbivore Limb Bones. *Paleobiology* 9:102-114.

1991 *Mammoths, Mastodonts and Elephants*. Cambridge University Press, Cambridge.

2002 Archaeological Methods for Reconstructing Human Predation on Terrestrial Vertebrates. In *A Fossil Record of Predation* edited by M. Kowalewski and P. Kelley, pp. 51-68. Paleontological Society Papers, Vol. 8. Paleontological Society, Pittsburgh, PA.

Haynes, G. and D. Stanford.
1984 On the Possible Utilization of Camelops by Early Man in North America. *Quaternary Research* 22: 216-230.

Hesse, B. and P. Wapnish
1985 *Animal Bone Archaeology: From Objectives to Analysis*. Taraxacum, Washington, D.C.

Hill, A.P.

1980 Early Postmortem Damage to the Remains of Some Contemporary East African Mammals. In *Fossils in the Making: Vertebrate Taphonomy and Paleoecology* edited by A.K. Behrensmeyer and A.P. Hill, pp. 131-152. University of Chicago Press, Chicago.

1989 Bone Modification by Modern Spotted Hyenas. In *Bone Modification*, edited by R. Bonnichsen and M. Sorg, pp. 169-178. Centre for the Study of the First Americans, University of Maine, Orono.

Hill, M.G.

2001 *Paleoindian Diet and Subsistence Behavior on the Northwestern Great Plains of North America.* Unpublished PhD Dissertation, University of Wisconsin, Madison.

Horton, D.R. and R.V.S. Wright

1981 Cuts on Lancefield Bones: Carnivorous *Thylacoleo*, Not Humans, the Cause. *Archaeology in Oceania* 16:73–80.

Houck, M.M.

1988 *Individualization of Tool Marks in Bone: A Scanning Electron and Light Incident Microscopy Study of Metal Knife Dynamics in Bone*. Unpublished MA thesis, Michigan State University, Michigan.

1998 Skeletal Trauma and Individualization of Knife Marks in Bone. In *Forensic Osteology: Advances in the Identification of Human Remains*, 2nd ed., edited by K.J. Reichs, pp. 410-424. Charles C. Thomas, Springfield, Illinois.

Hogue, S.H.

2006 Determination of Warfare and Interpersonal Conflict in the Protohistoric Period: A Case Study from Mississippi. *International Journal of Osteoarchaeology* 16:236-248.

Humphrey, J.H., and D.L. Hutchinson

2001 Macroscopic Characteristics of Hacking Trauma. *Journal of Forensic Sciences* 46(2):228-233.

Hurlbut, S.A.

2000 The Taphonomy of Cannibalism: A Review of Anthropogenic Bone Modification in the American Southwest. *International Journal of Osteoarchaeology* 10:4-26.

Hutchinson, D.L.

1996 Brief Encounters: Tatham Mound and the Evidence for Spanish and Native American Confrontation. *International Journal of Osteoarchaeology* 6:51-65.

Johnson, R.

1978 Paleo-Indian *Bison* Procurement and Butchering Patterns at Llano Estacado. *Plains Anthropologist*, Memoir 14, 23(82 Pt.2):98-105.

Johnson, E.
1989 Human Modified Bones from Early Southern Plains Sites. In *Bone Modification*, edited by R. Bonnichsen and M. Sorg, pp. 431-471. Centre for the Study of the First Americans, University of Maine, Orono.

Jolley, R.L.
1983 North American Historic Sites Zooarchaeology. *Historical Archaeology* 17(2):64-79.

Keating, K.A.
1990 Bone Chewing by Rocky Mountain Bighorn Sheep. *Great Basin Naturalist* 50(1):89.

Kierdorf, U.
1992 Fork Formation and Other Signs of Osteophagia on a Long Bone Swallowed by a Red Deer Stag (*Cervus elaphus*). *International Journal of Osteoarchaeology* 3(31):37-40.

1994 A Further Example of Long-Bone Damage Due to Chewing by Deer. *International Journal of Osteoarchaeology* 4(3):209-213.

Klippel, W.E., and J.A. Synstelien
2007 Rodents as Taphonomic Agents: Bone Gnawing by Brown Rats and Gray Squirrels. *Journal of Forensic Sciences* 52(4):765-773.

Klippel, W.E., L.M. Snyder, and P.W. Parmalee
1987 Taphonomy and Archaeologically Recovered Mammal Bone from Southeast Missouri. *Journal of Ethnobotany* 7:155-169.

Kockel, R.
1980 About the Appearance of Clues or Marks from Knife Blades. *AFTE Journal* 12(3):16-28.

Krausman, P.R. and J.A. Bissonette
1977 Bone-Chewing Behavior of Desert Mule Deer. *The Southwestern Naturalist* 22(1):149-150.

Landon, D.B.
1996 Feeding Colonial Boston: A Zooarchaeological Study. *Historical Archaeology* 30(1):58-95.

2005 Zooarchaeology and Historical Archaeology: Progress and Prospects. *Journal of Archaeological Method and Theory* 12(1):1-36.

Landt, M.J.
2007 Tooth Marks and Human Consumption: Ethnoarchaeological Mastication Research Among Foragers of the Central African Republic. *Journal of Archaeological Science* 34:1629-1640.

Laroulandie, V.
2002 Anthropogenic Versus Non-Anthropogenic Bird Bone Assemblages: New Criteria for their Distinction. In *Biosphere to Lithosphere: New Studies in Vertebrate Taphonomy*, edited by T. O'Connor, pp. 25-30. Oxbow Books, Oxford.

Larsen, C.S.
2002 Bioarchaeology: The Lives and Lifestyles of Past People. *Journal of Archaeological Research* 10(2):119-166.

Lensen, S.L.
1995 *Protohistoric Butchering at Four Oldman Dam Reservoir Sites*. Unpublished MA Thesis, Department of Archaeology, University of Calgary, Alberta.

Lewis, J.E.
2008 Identifying Sword Marks on Bone: Criteria for Distinguishing Between Cut Marks Made by Different Classes of Bladed Weapons. *Journal of Archaeological Science* 35(7):2001-2008 and electronic supplement. Electronic document, http://dx.doi.org/doi:10.1016/j.jas.2008.01.016, accessed September 2008.

Lotan, E.
2000 Feeding the Scavengers: Actualistic Taphonomy in the Jordan Valley, Israel. *International Journal of Osteoarchaeology* 10:407-425.

Lupo, K.D.
1994 Butchering Marks and Carcass Acquisition Strategies: Distinguishing Hunting from Scavenging in Archaeological Contexts. *Journal of Archaeological Science* 21:827-837.

Lupo, K.D. and J.F. O'Connell
2002 Cut and Tooth Mark Distributions on Large Animal Bones: Ethnoarchaeological Data from the Hadza and their Implications for Current Ideas about Early Human Carnivory. *Journal of Archaeological Science* 29:85-109.

Lyman, R.L.
1977 Analysis of Historic Faunal Remains. *Historical Archaeology* 11:67-73.

1987 Archaeofaunas and Butchery Studies: A Taphonomic Perspective. In *Advances in Archaeological Method and Theory*, Vol. 10, edited by M. B. Schiffer, pp. 249-337. Academic Press, San Diego.

1992 Prehistoric Seal and Sea-Lion Butchering on the Southern Northwest Coast. *American Antiquity* 57:246-261.

1994 *Vertebrate Taphonomy*. Cambridge University Press, Cambridge.

1995 A Study of Variation in the Prehistoric Butchery of Large Artiodactyls. In *Ancient Peoples and Landscapes*, edited by E. Johnson, pp. 233–253. Museum of Texas Tech University, Lubbock.

2004 The Concept of Equifinality in Taphonomy. *Journal of Taphonomy* 2(1): 15-26.

2005 Analyzing Cut Marks: Lessons from Artiodactyl Remains in the Northwestern United States. *Journal of Archaeological Science* 32:1722-1732.

2008 *Quantitative Paleozoology*. Cambridge University Press, Cambridge.

Lyman, R.L., and M.J. O'Brien
1998 The Goals of Evolutionary Archaeology: History and Explanation. *Current Anthropology* 39(5):615-652.

Maguire, J.M., D. Pemberton, and M.H. Collett
1980 The Makapansgat Limeworks Grey Breccia: Hominids, Hyaenas, Hystricids, or Hillwash? *Palaeontologia Africana* 23:75-98.

Marshall, L.G.
1989 Bone Modification and the Laws of Burial. In *Bone Modification* edited by R. Bonnichsen and Sorg, M. H., pp. 7–24. Centre for the Study of the First Americans, University of Maine, Orono.

Mead, E.M. and S. Meeks
1989 Photography of Archaeological and Paleontological Bone Specimens. In *Bone Modification*, edited by R. Bonnichsen and M. Sorg, pp. 267-281. Centre for the Study of the First Americans, University of Maine, Orono.

Micozzi, M.S.
1986 Experimental Study of Postmortem Change Under Held Conditions: Effects of Freezing, Thawing and Mechanical Injury. *Journal of Forensic Sciences* 31:953–61.

Miller, G.J.
1969 A Study of Cuts, Grooves, and Other Marks on Recent and Fossil Bones: 1. Animal Tooth Marks. *Tebiwa* 12:20-26. Papers of the Idaho State University Museum of Natural History, Pocatello.

1975 A Study of Cuts, Grooves, and Other Marks on Recent and Fossil Bones: 2. Weathering Cracks, Fractures, Splinters, and Other Similar Natural Phenomena. In *Lithic Technology: Making and Using Stone Tools*, edited by E.H. Swanson Jr., pp. 211-226. Aldine, Chicago.

Miller, J.
2000 Criteria for Identification of Toolmarks: Part II. *AFTE Journal* 32(2):116-131.

Miller, J. and M. McLean
1998 Criteria for Identification of Toolmarks. *AFTE Journal* 30(1):15-61.

Mirau, N.A., J. McMurchy, and C.R. Stewart (eds.)
1999 *Record in Stone: Familiar Projectile Points from Alberta*. 3rd ed. Archaeological Society of Alberta, Lethbridge Centre, Lethbridge, Alberta, CA.

Mitchell, P.D., Y. Nagar, and R. Ellenblum
2006 Weapon Injuries in the 12th Century Crusader Garrison of Vadum Iacob Castle, Galilee. *International Journal of Osteoarchaeology* 16:145-155.

Monahan, C.M.
1999 Comparing Apples and Oranges in the Plio-Pleistocene: Methodological Comments on "Meat-Eating by Early Hominids at the FLK 22 Zinjanthropus Site, Olduvai Gorge (Tanzania): An Experimental Approach Using Cut-Mark Data". *Journal of Human Evolution* 37:789-792.

Monks, G.G.
2001 Quit Blubbering: An Examination of Nuu'chah'nulth (Nootkan) Whale Butchery. *International Journal of Osteoarchaeology* 11:136-149.

Morlan, R.E.
1984 Toward the Definition of Criteria for the Recognition of Artificial Bone Alterations. *Quaternary Research* 22:160-171.

Novak, S.A. and D.D. Kollmann
2000 Perimortem Processing of Human Remains Among the Great Basin Fremont. *International Journal of Osteoarchaeology* 10:65-75.

Nichols, R.G.
1997 Firearm and Tool Mark Identification Criteria: A Review of the Literature. *Journal of Forensic Sciences* 42(3):466-474.

2003 Firearm and Tool Mark Identification Criteria: A Review of the Literature, Part II. *Journal of Forensic Sciences* 48(2):318-327.

2007 Defending the Scientific Foundations of the Firearms and Tool Mark Identification Discipline: Responding to Recent Challenges. *Journal of Forensic Sciences* 52(3):586-594.

Noe-Nygaard, N.
1987 Taphonomy in Archaeology with Special Emphasis on Man as a Biasing Factor. *Journal of Danish Archaeology* 6:7-62.

1989 Man-Made Trace Fossils on Bones. *Human Evolution* 4(6):461-491.

O'Connell, J.F.
1995 Ethnoarchaeology Needs a General Theory of Behavior. *Journal of Archaeological Research* 3(3):205-255.

O'Connell, J.F., K. Hawkes, K.D. Lupo, and N.G. Blurton-Jones
1988 Hadza Hunting, Butchering, and Bone Transport and Their Archaeological Implications. *Journal of Anthropological Research* 44:113-161.

O'Connor, T.
2000 *The Archaeology of Animal Bones*. Texas A&M University Press, College Station.

Oliver, J.S.
1989 Analogues and Site Context: Bone Damages from Shield Trap Cave (24CB91), Carbon County, Montana, USA. In *Bone Modification*, edited by R. Bonnichsen and M. Sorg, pp. 73-98. Center for the Study of the First Americans, University of Maine, Orono.

1993 Carcass Processing by the Hadza: Bone Breakage from Butchery to Consumption. In *From Bones to Behavior*, edited by J.Hudson, pp. 200-227. Center for Archaeological Investigations, Southern Illinois University, Carbondale.

1994 Estimates of Hominid and Carnivore Involvement in the FLK Zinjanthropus Fossil Assemblage: Some Socioecological Implications. *Journal of Human Evolution* 27:267–294.

Olsen, S.J.
1978 Bones from Awatovi, Northeastern Arizona: The Faunal Analysis. Reports of the Awatovi Expedition, Report No. 11. *Papers of the Peabody Museum of Archaeology and Ethnology* 70(1):1-34.

Olsen, S.L.
1987 Magdalenian Reindeer Exploitation at the Grotte des Eyzies, Southwest France. *Archaeozoologica* 1:171-182.

1988a Applications of Scanning Electron Microscopy in Archaeology. *Advances in Electronics and Electron Physics* 71:357-380.

1988b The Identification of Stone and Metal Tool Marks on Bone Artifacts. In *Scanning Electron Microscopy in Archaeology*, edited by S.L. Olsen, pp. 337-360. BAR International Series 452. British Archaeological Reports, Oxford.

1989 On Distinguishing Natural from Cultural Damage on Archaeological Antler. *Journal of Archaeological Science* 16:125-135.

Olsen, S.L. and P. Shipman
1988 Surface Modifications on Bone: Trampling vs. Butchering. *Journal of Archaeological Science* 15:535-553.

1994 Cut Marks and Perimortem Remains Treatment of Skeletal Remains on the Northern Plains. In *Skeletal Biology in the Great Plains: Migration, Warfare, Health, and Subsistance*, edited by D.W. Owsley and R.L. Jantz, pp. 377-387. Smithsonian Institution Press, Washington, D.C.

Perez, V.R., L.R. Godfrey, M. Nowak-Kemp, D.A. Burney, J. Ratsimbazafy, and N. Vasey
2005 Evidence of Early Butchery of Giant Lemurs in Madagascar. *Journal of Human Evolution* 49:722-742.

Pickering, T.R., C.P. Egeland, M. Domínguez-Rodrigo, C.K. Brain, and A.G. Schnell
2008 Testing the ''Shift in the Balance of Power'' Hypothesis at Swartkrans, South Africa: Hominid Cave Use and Subsistence Behavior in the Early Pleistocene. *Journal of Anthropological Archaeology* 27:30-45.

Pickering, T.R. and J. Wallis
1997 Bone Modifications Resulting from Captive Chimpanzee Mastication: Implications for the Interpretation of Pliocene Archaeological Faunas. *Journal of Archaeological Science* 24:1115-1127.

Pickering, T.R. and B. Hensley-Marschand
2008 Cutmarks and Hominid Handedness. *Journal of Archaeological Science* 35:310-315.

Piper, P.J. and T. O'Connor
2001 Urban Small Vertebrate Taphonomy: A Case Study from Anglo-Scandinavian York. *International Journal of Osteoarchaeology* 11:336-344.

Potts, R.
1982 *Lower Pleistocene Site Formation and Hominid Activities at Olduvai Gorge, Tanzania*. Unpublished Ph.D. dissertation, Harvard University, Cambridge, Massachusetts.

Potts, R. and P. Shipman
1981 Cut Marks Made by Stone Tools on Bones from Olduvai Gorge, Tanzania. *Nature* 291:577-580.

Pyszczyk, H.W.
1997 The Use of Fur Trade Goods by the Plains Indians, Central and Southern Alberta, Canada. *Canadian Journal of Archaeology* 21(1):45-84.

Raemsch, C.A.
1993 Mechanical Procedures Involved in Bone Dismemberment and Defleshing in Prehistoric Michigan. *Midcontinental Journal of Archaeology* 18: 216-244.

Ray, A.J.
1978 History and Archaeology of the Northern Fur Trade. *American Antiquity* 43(1):26-34.

Reeves, B.O.K.
1969 *Archaeological Site Inventory Data, EfPm-27*. Record on file, Archaeological Survey of Alberta, Edmonton.

Reeves, B.O.K and R. Anderson
1975 *Heritage Resources, Fish Creek Provincial Park, Site Inventory and Preliminary Evaluation*. Working Papers, Fish Creek Provincial Park, Prepared for Fish Creek Provincial Park Management Committee by Lombard North Group. Report on file, Archaeological Survey of Alberta, Edmonton.

Reichs, K.J.
1998 Postmortem Dismemberment: Recovery, Analysis, and Interpretation. In *Forensic Osteology: Advances in the Identification of Human Remains*, 2nd ed., edited by K.J. Reichs, pp. 353-388. Charles C. Thomas, Springfield, Illinois.

Reitz E.J and E.S. Wing
1999 *Zooarchaeology*. Cambridge Manuals in Archaeology. Cambridge University Press, Cambridge.

Rensberger, J.M. and H.B. Krentz
1988 Microscopic Effects of Predator Digestion on the Surfaces of Bones and Teeth. *Scanning Microscopy* 2:1541-1551.

Richardson, P.
1980 Carnivore Damage to Antelope Bones and its Archaeological Implications. *Palaeontologia Africana* 23:109-125.

Rose, J.J.
1983 A Replication Technique for Scanning Electron Microscopy: Applications for Anthropologists. *American Journal of Physical Anthropology* 62(3):255-261.

Runnings, A., C. Gustafson, and D. Bentley
1989 Use-Wear on Bone Tools: A Technique for Study Under the Scanning Electron Microscope. In *Bone Modification*, edited by R. Bonnichsen and M. Sorg, pp. 259-266. Center for the Study of the First Americans, University of Maine, Orono.

Russell, M.D. and F. LeMort
1986 Cutmarks on the Engis 2 Calvaria? *American Journal of Physical Anthropology* 69:317-323.

Sauer, N.J.
1984 Manner of Death: Skeletal Evidence of Blunt and Sharp Instrument Wounds. In *Human Identification*, edited by T.A. Rathbun and J.B. Buikstra, pp. 176-184. Charles C. Thomas, Springfield, Illinois.

1998 The Timing of Injuries and Manner of Death: Distinguishing Among Antemortem, Perimortem and Postmortem Trauma. In *Forensic Osteology*, 2nd ed., edited by K.J. Reichs, pp. 321-332. Charles C. Thomas, Springfield, Illinois.

Savage, S.B.
1995 *Bison Procurement and Processing Strategies: Contrasts in Two Non-Kill Sites on the Southern Plains*. Unpublished PhD dissertation, University of Oklahoma, Norman.

Schiffer, M.B
1972 Archaeological Context and Systemic Context. *American Antiquity* 37:156-165.

1976 *Behavioral Archaeology*. Academic Press, New York.

1987 *Formation Processes of the Archaeological Record*. University of New Mexico Press, Albuquerque.

Schrenk, F. and J.M. Maguire
1988 Actualistic SEM Studies on the Makapansgat Limeworks Grey Breccia Bone Assemblage, Transvaal, South Africa. In *Scanning Electron Microscopy in Archaeology*, edited by S.L. Olsen, pp. 287-301. BAR International Series 452. British Archaeological Reports, Oxford.

Schultz, M.
1997 Microscopic Investigation of Excavated Skeletal Remains: A Contribution to Paleopathology and Forensic Medicine. In *Forensic Taphonomy: The Postmortem Fate of Human Remains*, edited by W.D. Haglund and M.H. Sorg, pp. 201-222. CRC Press, Boca Raton, Florida.

Scott, E.C.
1982 Replica Production for Scanning Electron Microscopy: A Test of Materials Suitable for Use in Field Settings. *Journal of Microscopy* 125 (3):337-341.

Selvaggio, M.M.
1994 Carnivore Tooth Marks and Stone Tool Butchery Marks on Scavenged Bones: Archaeological Implications. *Journal of Human Evolution* 27:215–228.

Selvaggio, M.M. and J. Wilder
2001 Identifying the Involvement of Multiple Carnivore Taxa with Archaeological Bone Assemblages. *Journal of Archaeological Science*, 28(5):465-470.

Shipman, P.
1981a *Life History of a Fossil: An Introduction to Taphonomy and Paleoecology*. Harvard University Press, Cambridge, Massachusetts.

1981b Applications of Scanning Electron Microscopy to Taphonomic Problems. *Annals of the New York Academy of Sciences* 376:357-386.

1983 Early Hominid Lifestyles: Hunting and Gathering or Foraging and Scavenging? In *Animals and Archaeology: 1. Hunters and Their Prey*, edited by J. Clutton-Brock and C. Grigson, pp. 51-62. BAR International Series 163. British Archaeological Reports, Oxford.

1986 Scavenging or Hunting in Early Hominids: Theoretical Framework and Tests. *American Anthropologist, New Series* 88(1):27-43.

1987 Response to R. Lee Lyman. *American Anthropologist*, *New Series* 89(3):715-717.

1988 Actualistic Studies of Animal Resources and Hominid Activities. In *Scanning Electron Microscopy and Archaeology*, edited by S. L. Olsen, pp. 261-285. BAR International Series 452. British Archaeological Reports, Oxford.

Shipman, P. and J. Rose
1983a Early Hominid Hunting, Butchering, and Carcass-Processing Behaviours: Approaches to the Fossil Record. *Journal of Anthropological Archaeology* 2:57-98.

1983b Evidence of Butchery and Hominid Activities at Torralba and Ambrona: An Evaluation Using Microscopic Techniques. *Journal of Archaeological Science* 10:465-474.

1984 Cut Mark Mimics on Modern and Fossil Bovid Bones. *Current Anthropology* 25:116-117.

1988 Bone Tools: An Experimental Approach. In *Scanning Electron Microscopy and Archaeology*, edited by S. L. Olsen, pp. 303-335. BAR International Series 452. British Archaeological Reports, Oxford.

Shipman, P., D.C. Fisher, and J. Rose
1984 Mastodon Butchery: Microscopic Evidence of Carcass-Processing and Bone Tool Use. *Paleobiology* 10:358-365.

Simpson, G.C.
1963 Historical Science. In *The Fabric of Geology*, edited by C.C. Albritton Jr., pp. 24-48. Addison-Wesley, Readin, Massachusetts.

Singer, R.
1956 The "Bone Tools" from Hopefield. *American Anthropologist* 58:1127-1134.

Smith, M.J. and M.B. Brickley
2004 Analysis and Interpretation of Flint Tool marks Found on Bones from West Tump Long Barrow, Gloucestershire. *International Journal of Osteoarchaeology* 14(1):18-33.

Smith, M.J., M.B. Brickley, and S.L. Leach
2007 Experimental Evidence for Lithic Projectile Injuries: Improving Identification of an Under-Recognised Phenomenon. *Journal of Archaeological Science* 34:540-553.

Smith, O.C., Elayne J. Pope, and Steven A. Symes
2003 Look Until You See: Identification of Trauma in Skeletal Material. In *Hard Evidence: Case Studies in Forensic Anthropology*, edited by D.W. Steadman, pp. 138-154. Pearson Education, New Jersey.

Smith, T., E.M.Calder, and B.O.K.Reeves
1977 *Archaeological Excavations, EfPm-27, Fish Creek Provincial Park*. Prepared for Lombard North Group by Lifeways of Canada Limited. Report on file with the Archaelogical Survey of Alberta, Edmonton.

Springer, E.
1995 Tool Mark Examinations: A Review of its Development in the Literature. *Journal of Forensic Sciences* 40(6):964-968.

Stevens, G.C. and J. Wakely
1993 Diagnostic Criteria for Identification of Seashell as a Trephination Implement. *International Journal of Osteoarchaeology* 3(3):167-176.

Steward, J.H.
1942 The Direct Historical Approach to Archaeology. *American Antiquity* 7(4):337-343.

Stodder, A.L.W.
2008 Taphonomy and the Nature of Archaeological Assemblages. In *Biological Anthropology of the Human Skeleton*, 2nd ed., edited by M.A. Katzenberg and S.R. Saunders, pp. 71-114. Wiley, Hoboken, New Jersey.

Stone, D.E.
2006 *Specific Lithic Modification of Bone During Butchering: A Scanning Electron Microscopy Analysis*. Unpublished Masters Thesis, University of Alaska, Anchorage.

Sutcliffe, A.
1970 Spotted Hyena: Crusher, Gnawer, Digester, and Collector of Bones. *Nature* 227:1110-1113.

1973 Similarity of Bones and Antlers Gnawed by Deer to Human Artifacts. *Nature* 246:428-430.

Symes, S.A., H.E. Berryman, and O.C. Smith
1998 Saw Marks in Bone: Introduction and Examination of Residual Kerf Contour. In *Forensic Osteology: Advances in the Identification of Human Remains*, 2nd ed., edited by K.J. Reichs, pp. 389-409. Charles C. Thomas, Springfield, Illinois.

Symes, S.A., J.A. Williams, E.A. Murray, J.M. Hoffman, T.D. Holland, J. Saul, F. Saul, and E.J. Dope
2002 Sharp Force Trauma in Suspected Cases of Mutilation and Dismemberment. In *Advances in Forensic Taphonomy*, edited by W.D. Haglund and M.H. Sorg, pp. 404-434. CRC Press, Boca Raton, Florida.

Tappen, N.C.
1969 The Relationship of Weathering Cracks to Split-Line Orientation in Bone. *American Journal of Physical Anthropology* 31:191-198.

Todd, L.C., M.G. Hill, D.J. Rapson, and G.C. Frison
1993 *Cut Marks, Impacts, and Carnivores at the Casper Bison Bonebed*. Proceedings of the 1993 Bone Modification Conference, Hot Springs, South Dakota

Toth, N. and M. Woods
1989 Molluscan Shell Knives and Experimental Cut-Marks on Bones. *Journal of Field Archaeology* 16:250-255.

Trolle-Lassen, T.
1987 Human Exploitation of Fur Animals in Mesolithic Denmark: A Case Study. *Archaeozoologia* 2:85–102.

Tucker, B.K., D.L. Hutchinson, M.F.G. Gilliland, T.M. Charles, H.J. Daniel and L.D. Wolfe
2001 Microscopic Characteristics of Hacking Trauma. *Journal of Forensic Sciences* 46:234-240.

Turner, C.G.
1983 Taphonomic Reconstructions of Human Violence and Cannibalism Based on Mass Burials in the American Southwest. In *Carnivores, Human Scavengers, and Predators: A Question of Bone Technology*, edited by G.M. LeMoine and A.S. MacEachern, pp. 219-240. Chacmool Archaeological Association, University of Calgary, Alberta.

Ubelaker, D.H.
1997 Taphonomic Applications in Forensic Anthropology. In *Forensic Taphonomy: The Postmortem Fate of Human Remains*, edited by W.D. Haglund and M.H. Sorg, pp. 77-90. CRC Press, Boca Raton, Florida.

Ubelaker, D.H., and B.J. Adams
1995 Differentiation of Perimortem and Postmortem Trauma Using Taphonomic Indicators. *Journal of Forensic Sciences* 40(3):509-512.

Ubelaker, D.H., and J.E. Smialek
2003 The Interface of Forensic Anthropology and Forensic Pathology in Trauma Interpretation. In *Hard Evidence: Case Studies in Forensic Anthropology*, edited by D.W. Steadman, pp. 138-154. Pearson Education, New Jersey.

Vickers, J.R.
1986 *Alberta Plains Prehistory: A Review*. Archaeological Survey of Alberta Occaisional Paper No.27. Alberta Culture Historical Resources Division, Edmonton, Alberta.

Villa, P., C. Bouville, J. Courtin, D. Helmer, E. Mahieu, P. Shipman, G. Belluomini, and M. Branca
1986 Cannibalism in the Neolithic. *Science* 233:431–437.

Vivian, B.C., A. Dow, and B.O.K. Reeves
2005a *Historical Resource Conservation Excavations EgPn-430. Volume 1: Areas Two and Three. Final report*. Prepared by Lifeways of Canada Ltd. for Crestmont Developments Inc. Permit 2003-097. Report on file, Archaeological Survey of Alberta, Edmonton.

2005b *Historical Resource Conservation Excavations EgPn-430. Volume 2: Area Six. Final report*. Prepared by Lifeways of Canada Ltd. for Crestmont Developments Inc. Permit 2003-097. Report on file, Archaeological Survey of Alberta, Edmonton.

Wakely, J.
1989 Scanning Electron Microscope Study of Normal Vertebrae and Ribs from Early Medieval Human Skeletons. *Journal of Archaeological Science* 16:627-642.

Walde, D., D. Boland, and M. Schatz
2001 *The Fish Creek Archaeological project: A Progress Report on Work Conducted Under Permits 98-042, 99-054, and 00-083*. Report on file, Archaeological Survey of Alberta, Edmonton.

Walker, P.L. and J.C Long
1977 An Experimental Study of the Morphological Characteristics of Tool Marks. *American Antiquity* 42(4):605-616.

Walsh-Haney, H.A.
1999 Sharp-Force Trauma Analysis and the Forensic Anthropologist: Techniques Advocated by William R. Maples, Ph.D. *Journal of Forensic Sciences* 44(4):720-723.

Warrick, G. and P.R. Krausman
1986 Bone-Chewing by Desert Bighorn Sheep. *The Southwestern Naturalist* 31(3):414.

Watson, J.A.L. and H.M. Abbey
1986 The Effects of Termites (Isoptera) on Bone: Some Archaeological Implications. *Sociobiology* 11:245-254.

West, J.A and J. Louys
2007 Differentiating Bamboo from Stone Tool Cut Marks in the Zooarchaeological Record, with a Discussion on the Use of Bamboo Knives. *Journal of Archaeological Science* 34:512-518.

Wheat, J.B.
1979 The Jurgens Site. *Plains Anthropologist*, Memoir 15, 24(84):1-153.

White, T.D.
1986 Cut Marks on the Bodo Cranium: A Case of Prehistoric Defleshing. *American Journal of Physical Anthropology* 69:503–509.

1992 *Prehistoric Cannibalism at Mancos 5MTUMR-2346*. Princeton University Press, Princeton.

White, T.D. and N. Toth
1989 Engis: Preparation Damage, Not Ancient Cut Marks. *American Journal of Physical Anthropology* 78:361-367.

Wickham, M.
2003 *Progress Report Efpm-27; Fish Creek Provincial Park 2002, Permit 2002-050*. Report on file with the Archaeological Survey of Alberta, Edmonton.

2005 *EfPm-27: Faunal Analysis of a Late Prehistoric Bison Bone Bed in Fish Creek Provincial Park, Calgary, Southwest Alberta.* Unpublished MA Thesis, Department of Archaeology, University of Calgary, Alberta.

Wickham, M. and D. Walde
2002 *Progress Report EfPm-27: Fish Creek Provincial Park 2001, Permit 2001-104*. Report on file, Archaeological Survey of Alberta, Edmonton.

Willis, L.M., M.I. Eren, and T.C. Rick
2008 Does Butchering Fish Leave Cut Marks? *Journal of Archaeological Science* 35:1438-1444.

Wylie, A.
1985 The Reaction Against Analogy. In *Advances in Archaeological Method and Theory*, Vol. 8, edited by M.B. Schiffer, pp. 63-111. Academic Press, San Diego.

Young, D.E.
1989 How Powerful are Archaeological Inferences Based Upon Experimental Replication? In *Bone Modification*, edited by R. Bonnichsen and M. Sorg, pp. 53-60. Centre for the Study of the First Americans, University of Maine, Orono.

Yvinec, J.H., M. Coutureau, C. Tomé, C. Beauval, and J.G. Ferrié
2003 *Archeozoo: Digitized Skeletons: Bison bison*. Electronic document, http://www.archeozoo.org/en-article134.html, accessed September 2008.

Appendix A

Mapped Cut Marks from EfPm-27

Table A1. Distribution of Mapped Cut Marks from EfPm-27

Element	Side	View	Cat#
Astragalus	Left	Medial view	624
Astragalus	Right	Caudal view & medial view	631
Astragalus	Left	Medial view	632
Astragalus	Left	Medial view	630 - multiple sets
Astragalus	Left	Medial view	634 - multiple sets
Astragalus	Left	Medial view	638
Atlas vertebra	Axial	Caudal view	249
Atlas vertebra	Axial	Caudal view	251
Calcaneus	Right	Lateral view	618
Cranium	Axial	Dorsal view	201
Cranium	Axial	Ventral view	203
Dentary	Left	Lateral view	206
Dentary	Left	Medial view	208
Dentary	Right	Medial view	209
Dentary	Left	Medial view	210
Dentary	Right	Lateral view	212
Dentary	-	Lateral view	216
Dentary	Right	Medial view	218
Dentary	-	Medial view	221
Dentary	Right	Lateral view	222
Dentary	Left	Medial view	226 - multiple sets
Dentary	Left	Medial view	227
Dentary	Right	Medial view	229
Dentary	Left	Medial view	231

Element	Side	View	Cat#
Dentary	Left	Medial view	232
Dentary	Left	Medial view	233
Dentary	Left	Lateral view	236
Dentary	-	Medial view	239
Femur	Left	Medial view	556
Femur	Right	Medial view	558
Femur	Left	Caudal view	560
Femur	Left	Caudal view	561
Femur	Left	Cranial view	564
Femur	Right	Cranial view	565
Femur	Right	Medial view	566
Femur	Left	Cranial view	570
Humerus	Right	Cranial view	505
Humerus	Left	Lateral view	508
Hyoid	-	Medial view	240
Hyoid	-	Medial view	241
Hyoid	-	Medial view	242
Hyoid	-	Medial view	243
Hyoid	-	Lateral view & medial view	244 - multiple sets
Hyoid	-	Medial view	245
Intermediate carpal	Left	Cranial view	615
Lumbar vertebra	Left side	Lateral view	421
Lumbar vertebra	-	Cranial view & dorsal view	422
Lumbar vertebra	Right side	Lateral view	427
Lumbar vertebra	-	Caudal view	432
Lumbar vertebra	Left side	Lateral view	433
Lumbar vertebra	Left side	Lateral view	434
Lumbar vertebra	Right side	Lateral view	436
Lumbar vertebra	Left side	Lateral view	438
Lumbar vertebra	-	Dorsal view	820
Lumbar vertebra	Right side	Lateral view	836
Metacarpal	-	Cranial view	588
Metacarpal	-	Cranial view	595
Metatarsal	Left	Caudal view	602

Element	Side	View	Cat#
Metatarsal	Right	Caudal view	604
Metatarsal	Right	Medial view	605
Metatarsal	-	Caudal view	606
Metatarsal	-	Cranial view	610
Os coxa	-	Ventral view	531
Os coxa	Left	Lateral view	536 - multiple sets
Os coxa	-	Dorsal view	539
Os coxa	Right	Lateral view	548
Os coxa	-	Ventral view	551
Os coxa	Left	Lateral view	552
Os coxa	-	Ventral view	553
Os coxa	-	Dorsal view	554
Radius	Left	Cranial view	515
Radius	Right	Cranial view	519
Radius	Left	Cranial view	520
Rib	Left	Lateral view	447 - multiple sets
Rib	Right	Lateral view	452
Rib	Left	Lateral view	457
Rib	Right	Medial view	469
Rib	Right	Lateral view	475
Rib	Right	Medial view	487
Rib	Left	Medial view	491
Rib	Left	Lateral view	685
Rib	Right	Lateral view	686
Rib	Right	Medial view	687
Rib	Right	Dorsal view	694
Rib	Left	Lateral view	712 - multiple sets
Rib	Left	Lateral view	720
Rib	Left	Lateral view	724 - multiple sets
Rib	Left	Lateral view	726
Rib	Left	Lateral view	737
Rib	Left	Lateral view	740
Rib	Left	Lateral view	746 - multiple sets
Rib	Left	Lateral view	821
Rib	Right	Medial view	824
Rib	Right	Medial view	824
Scapula	Right	Caudal view	844
Second phalanx	-	Abaxial view	615
Thoracic vertebrae	Right side	Lateral view (complete bones)	215

Element	**Side**	**View**	**Cat#**
Thoracic vertebrae	Right side	Lateral view	238
Thoracic vertebrae	Right side	Spinous process (lateral view)	239
Thoracic vertebrae	-	Cranial view	252
Thoracic vertebrae	Left side	Lateral view	254
Thoracic vertebrae	Left side	Lateral view	257
Thoracic vertebrae	Left side	Lateral view	261
Thoracic vertebrae	Right side	Lateral view	263
Thoracic vertebrae	Right side	Lateral view	263
Thoracic vertebrae	Left side	Lateral view	266
Thoracic vertebrae	Left side	Lateral view	266
Thoracic vertebrae	-	Caudal view	267
Thoracic vertebrae	Right side	Lateral view	268
Thoracic vertebrae	Right side	Lateral view	270
Thoracic vertebrae	-	Cranial view	271
Thoracic vertebrae	Right side	Lateral view	272
Thoracic vertebrae	Right side	Lateral view	279
Thoracic vertebrae	Left side	Lateral view	280
Thoracic vertebrae	Left side	Lateral view	281
Thoracic vertebrae	Left side	Lateral view	282
Thoracic vertebrae	Left side	Lateral view	283
Thoracic vertebrae	Right side	Lateral view	284
Thoracic vertebrae	-	Cranial view	286
Thoracic vertebrae	Right side	Lateral view	287

Element	Side	View	Cat#
Thoracic vertebrae	Right side	Lateral view	291
Thoracic vertebrae	Right side	Lateral view	293
Thoracic vertebrae	Right side	Lateral view	298
Thoracic vertebrae	Right side	Lateral view	300
Thoracic vertebrae	Right side	Lateral view	303
Thoracic vertebrae	Right side	Lateral view	304
Thoracic vertebrae	Right side	Lateral view	305
Thoracic vertebrae	-	Cranial view	306
Thoracic vertebrae	Left side	Lateral view	308
Thoracic vertebrae	-	Cranial view	309
Thoracic vertebrae	Right side	Lateral view	314
Thoracic vertebrae	Right side	Spinous process (lateral view)	316
Thoracic vertebrae	Left side	Spinous process (lateral view)	317
Thoracic vertebrae	Left side	Lateral view	318
Thoracic vertebrae	Left side	Lateral view	323
Thoracic vertebrae	Left side	Lateral view	326
Thoracic vertebrae	Right side	Lateral view	327
Thoracic vertebrae	Left side	Lateral view	328
Thoracic vertebrae	Left side	Lateral view	329
Thoracic vertebrae	Right side	Lateral view	333
Thoracic vertebrae	Left side	Lateral view	334
Thoracic vertebrae	Left side	Lateral view	336
Thoracic vertebrae	Left side	Spinous process (lateral view)	338

Element	**Side**	**View**	**Cat#**
Thoracic vertebrae	Left side	Lateral view	339
Thoracic vertebrae	Right side	Lateral view	341
Thoracic vertebrae	Right side	Lateral view	342
Thoracic vertebrae	Left side	Lateral view	343
Thoracic vertebrae	Right side	Lateral view	344
Thoracic vertebrae	Left side	Lateral view	345
Thoracic vertebrae	Right side	Lateral view	347
Thoracic vertebrae	-	Cranial view	348
Thoracic vertebrae	-	Cranial view	350
Thoracic vertebrae	Right side	Lateral view	354
Thoracic vertebrae	Left side	Lateral view	355
Thoracic vertebrae	Right side	Lateral view	360
Thoracic vertebrae	Right side	Lateral view	361
Thoracic vertebrae	Left side	Lateral view	362
Thoracic vertebrae	Right side	Lateral view	365
Thoracic vertebrae	Right side	Lateral view (complete bones)	366
Thoracic vertebrae	Right side	Lateral view	368
Thoracic vertebrae	Right side	Lateral view	369
Thoracic vertebrae	Left side	Lateral view	370
Thoracic vertebrae	-	Caudal view	371
Thoracic vertebrae	Right side	Lateral view	372
Thoracic vertebrae	Left side	Lateral view (complete bones)	373
Thoracic vertebrae	Left side	Lateral view	374

Element	Side	View	Cat#
Thoracic vertebrae	Left side	Lateral view (complete bones)	375
Thoracic vertebrae	Left side	Lateral view	378
Thoracic vertebrae	Left side	Lateral view	380
Thoracic vertebrae	Left side	Lateral view	381
Thoracic vertebrae	Left side	Lateral view	382
Thoracic vertebrae	Right side	Lateral view	383
Thoracic vertebrae	Right side	Lateral view	384
Thoracic vertebrae	Right side	Lateral view	386
Thoracic vertebrae	Right side	Spinous process (lateral view)	388
Thoracic vertebrae	Right side	Lateral view	390
Thoracic vertebrae	Right side	Lateral view	391
Thoracic vertebrae	Left side	Lateral view	393
Thoracic vertebrae	Left side	Lateral view	396
Thoracic vertebrae	Right side	Lateral view	398
Thoracic vertebrae	Right side	Lateral view	404
Thoracic vertebrae	Right side	Lateral view	405
Thoracic vertebrae	Left side	Lateral view	406
Thoracic vertebrae	Left side	Lateral view	407
Thoracic vertebrae	Right side	Lateral view	408
Thoracic vertebrae	Right side	Lateral view	494
Thoracic vertebrae	Right side	Lateral view (complete bones)	818
Thoracic vertebrae	Right side	Spinous process (lateral view)	819
Thoracic vertebrae	Right side	Lateral view	832

Element	Side	View	Cat#
Thoracic vertebrae	Right side	Lateral view	833
Thoracic vertebrae	Right side	Lateral view	834
Thoracic vertebrae	Left side	Lateral view	835
Thoracic vertebrae	Left & right sides	Lateral view – cut marks on both sides	260 - multiple sets
Thoracic vertebrae	Right side	Lateral view – articulating series (incomplete bones)	275, 276, 277, 278
Thoracic vertebrae	Right side	Lateral view (complete bones)	297 - multiple sets
Thoracic vertebrae	Right side	Lateral view – articulating series (incomplete bones)	301, 302
Thoracic vertebrae	Left & right sides	Lateral view – cut marks on both sides	315 - multiple sets
Thoracic vertebrae	Left & right sides	Lateral view – cut marks on both sides	331 - multiple sets
Thoracic vertebrae	Left & right sides	Lateral view – cut marks on both sides	340 - multiple sets
Thoracic vertebrae	Left & right sides	Lateral view – cut marks on both sides	359 - multiple sets
Thoracic vertebrae	Left & right sides	Lateral view – cut marks on both sides	387 - multiple sets
Thoracic vertebrae	Left & right sides	Lateral view – cut marks on both sides	389 - multiple sets
Thoracic vertebrae	Left side	Lateral view – articulating series (incomplete bones)	394, 395
Thoracic vertebrae	Left & right sides	Lateral view – articulating series with cut marks on both sides (complete bones)	401, 401 - multiple sets
Thoracic vertebrae	Left & right sides	Lateral view – articulating series with cut marks on both sides (complete bones)	402, 403 - multiple sets
Thoracic vertebrae	Left & right sides	Spinous process (lateral view)– cut marks on both sides	453 - multiple sets
Thoracic vertebrae	-	Cranial view	831 - chop
Thoracic vertebrae	Right side	Lateral view – articulating series (incomplete bones)	833, 834, 832
Tibia	Right	Cranial view	567
Tibia	Right	Cranial view	572
Tibia	Left	Caudal view	580
Tibia	Left	Lateral view	581
Tibia	Left	Medial view	583

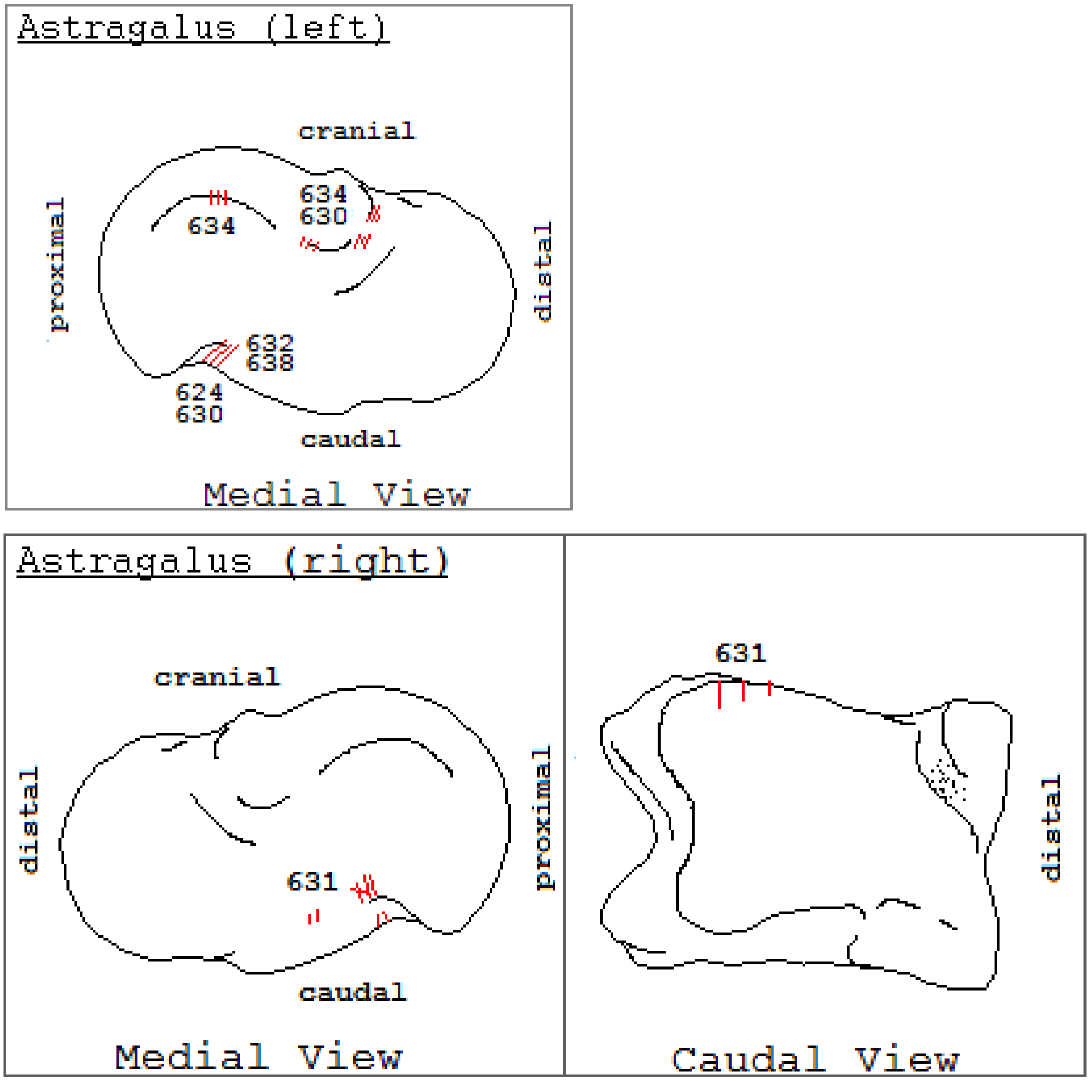

Figure A1. Astragalus cut mark distribution.

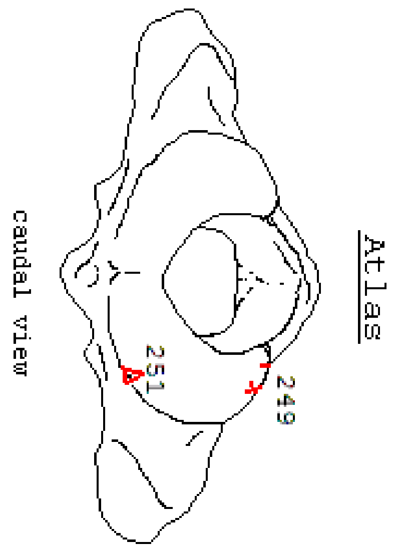

Figure A2. Atlas vertebra cut mark distribution.

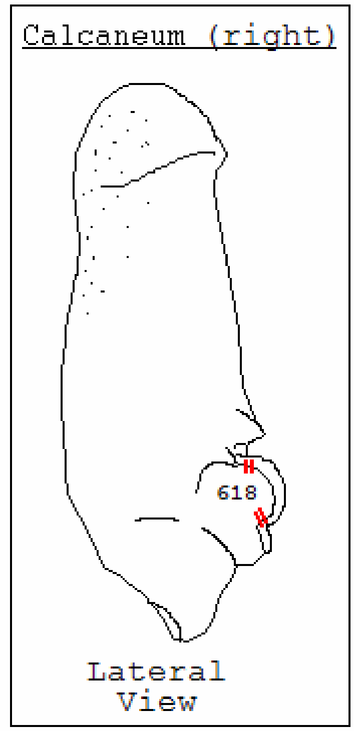

Figure A3. Calcaneus cut mark distribution.

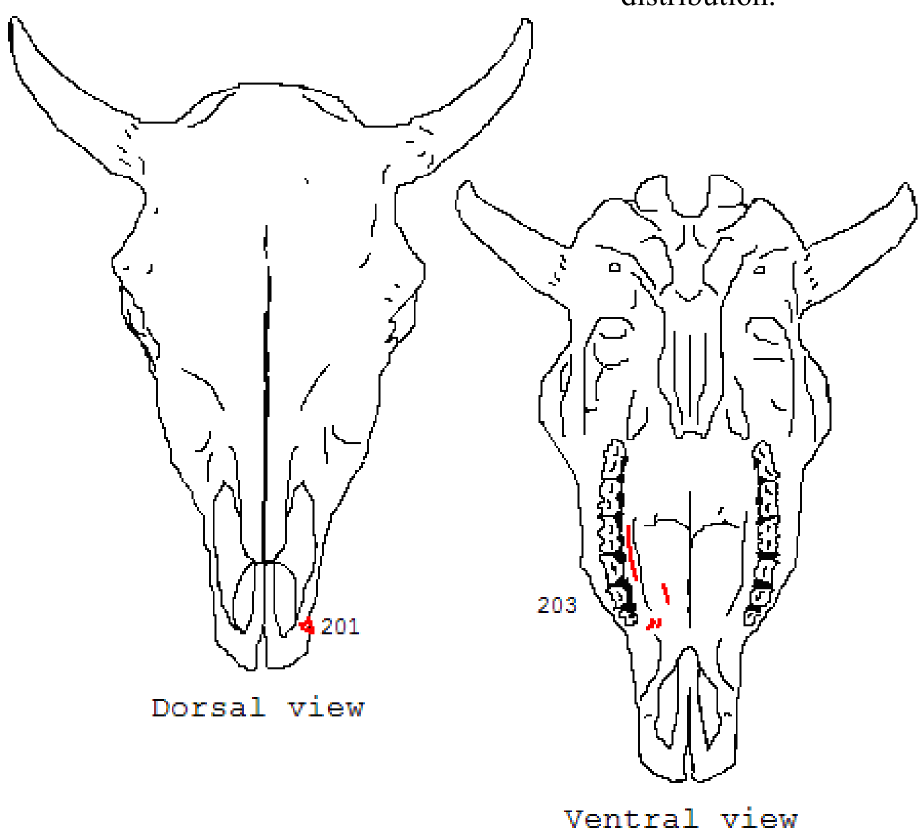

Figure A4. Cranium cut mark distribution.

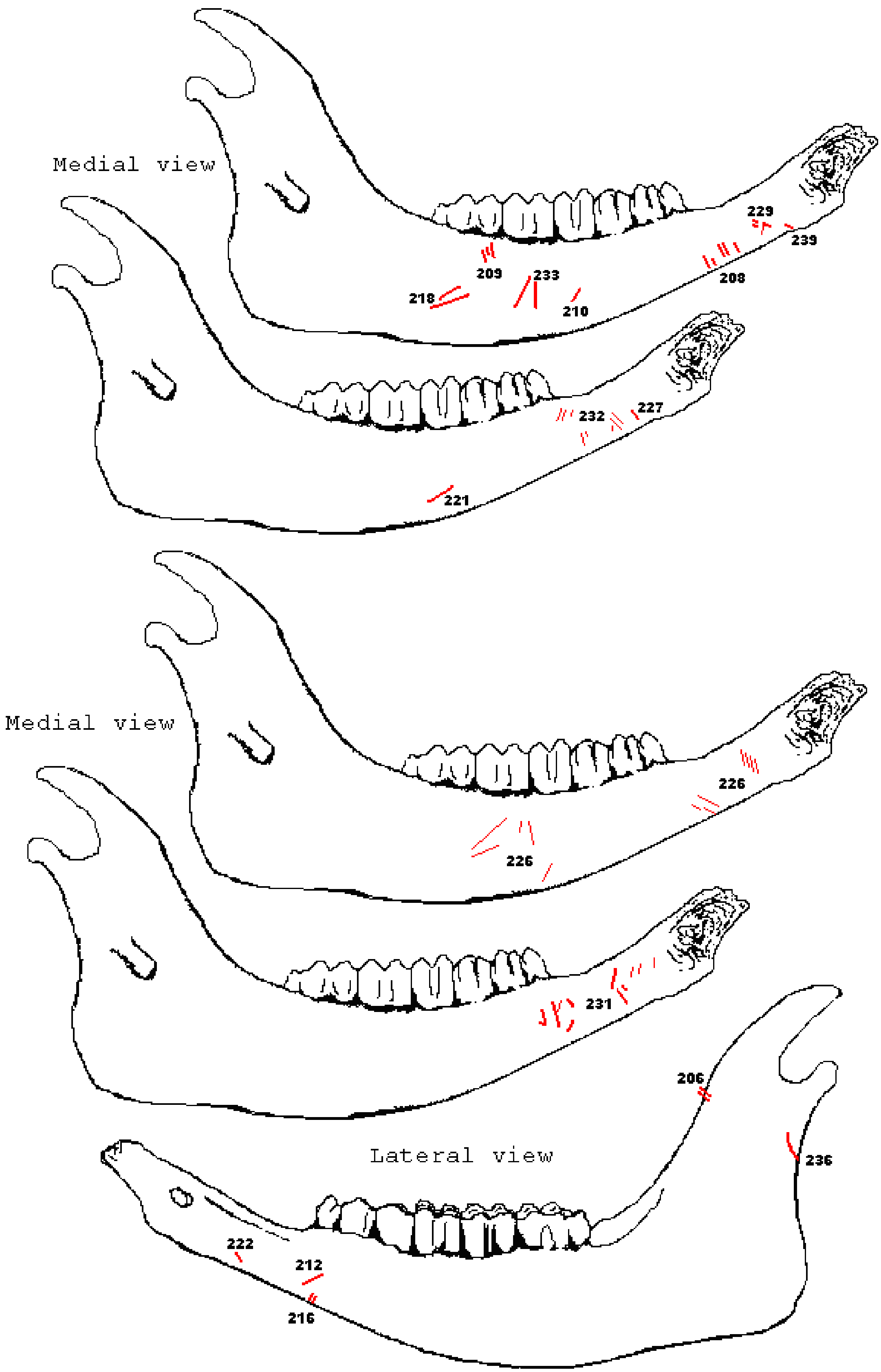

Figure A5. Dentary cut mark distribution.

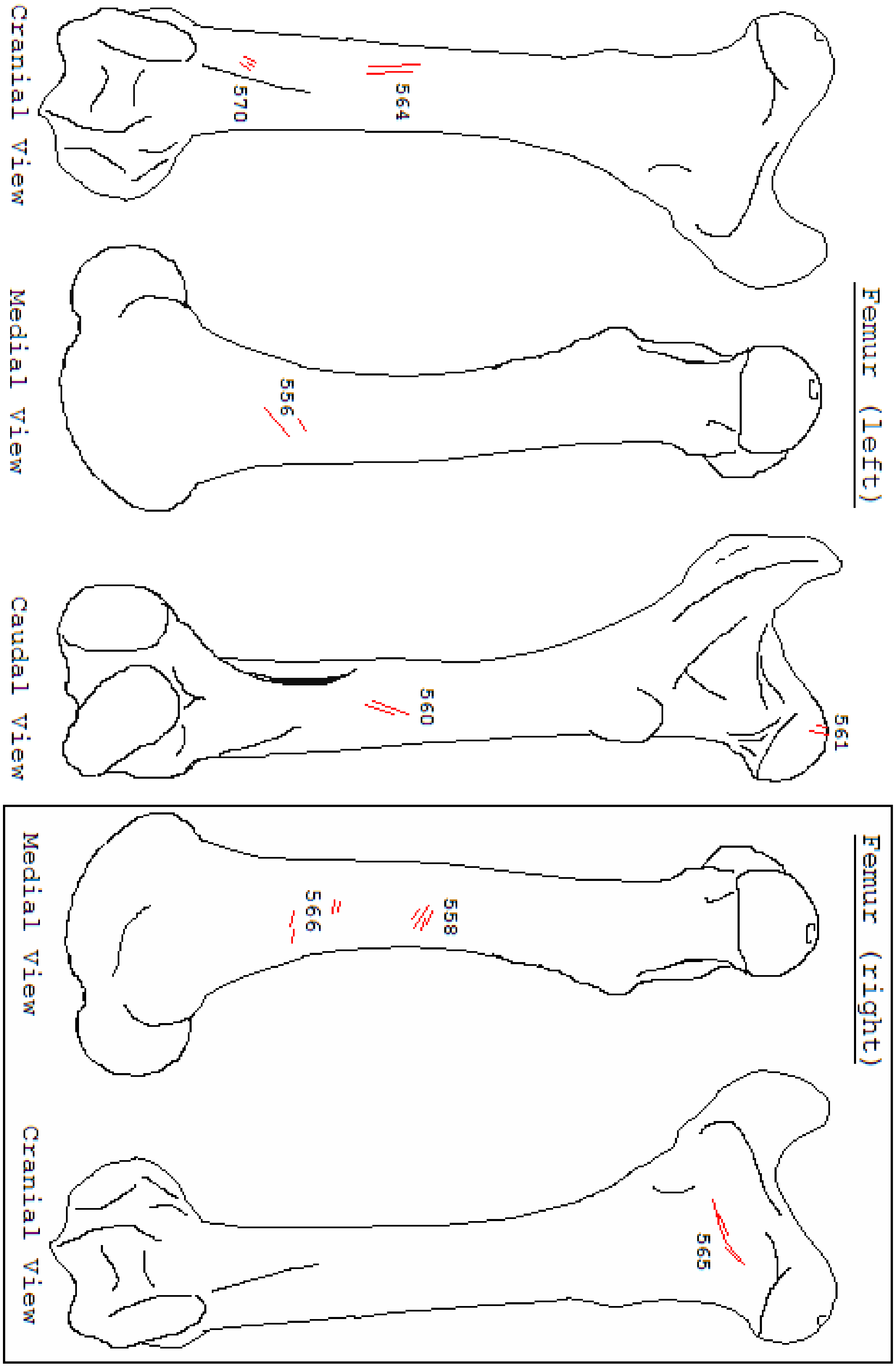

Figure A6. Femur cut mark distribution.

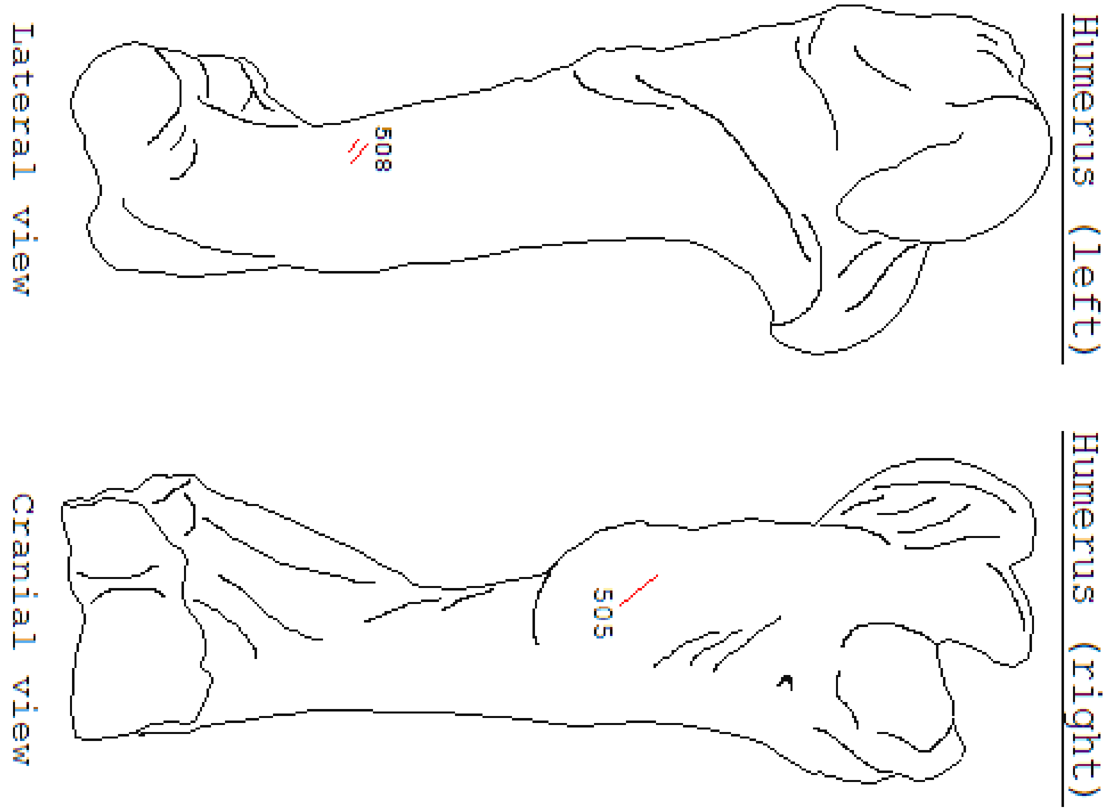

Figure A7. Humerus cut mark distribution.

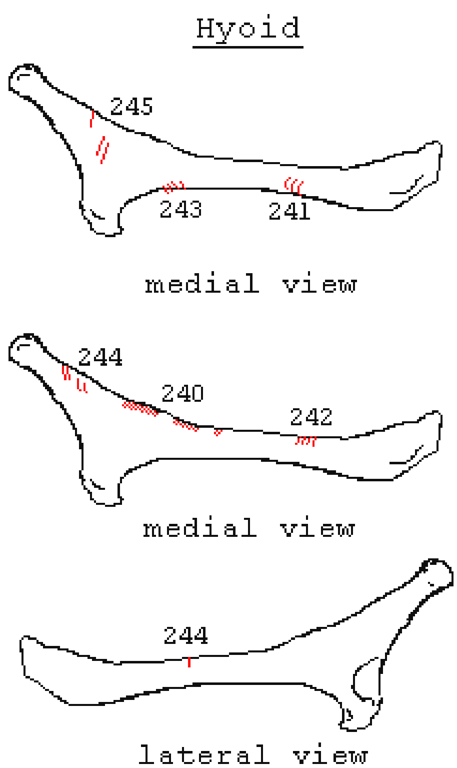

Figure A8. Hyoid cut mark distribution.

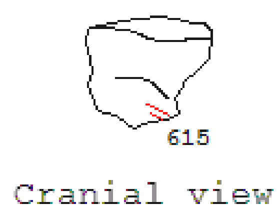

Figure A9. Intermediate carpal cut mark distribution.

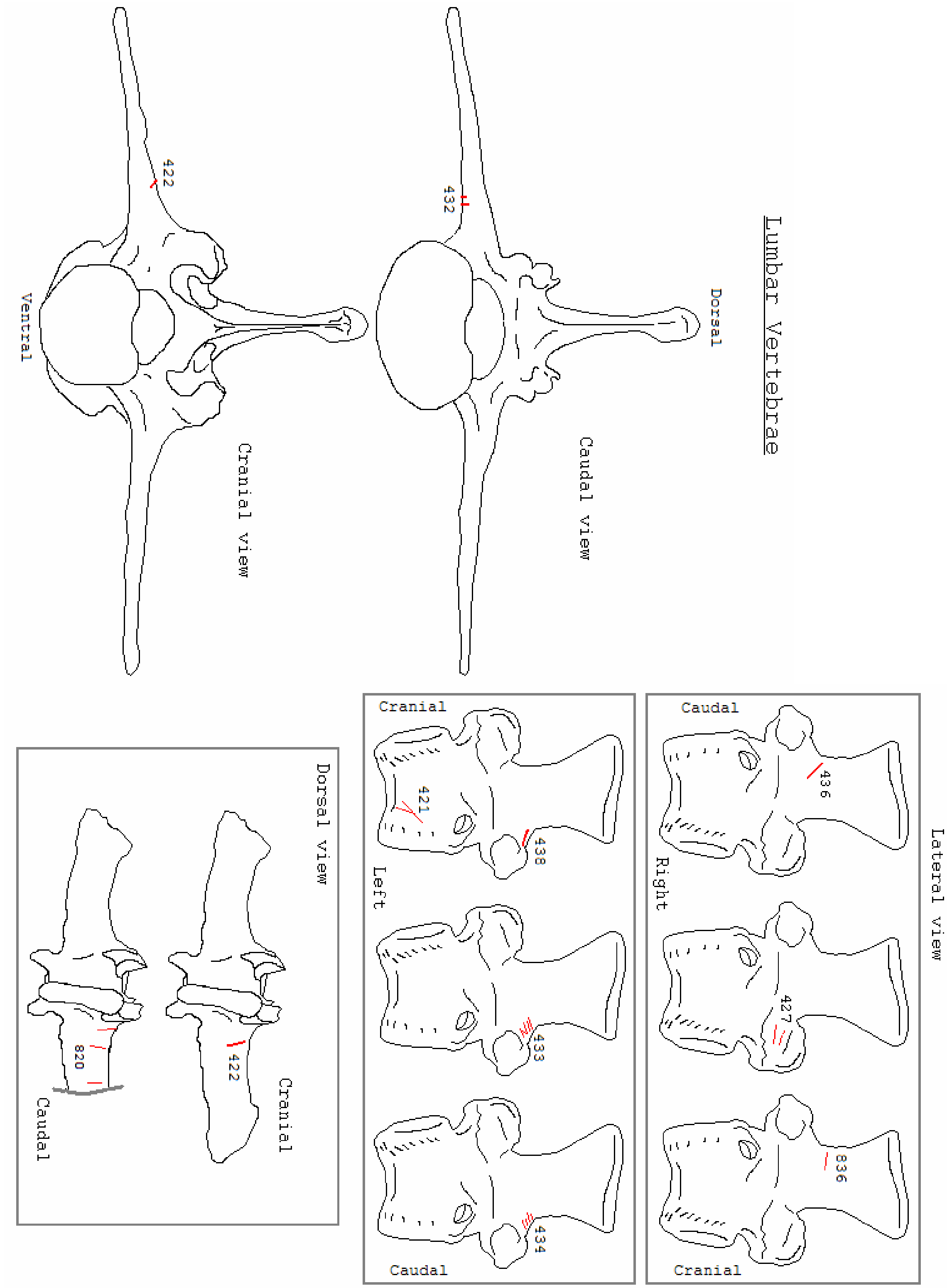

Figure A10. Lumbar vertebra cut mark distribution.

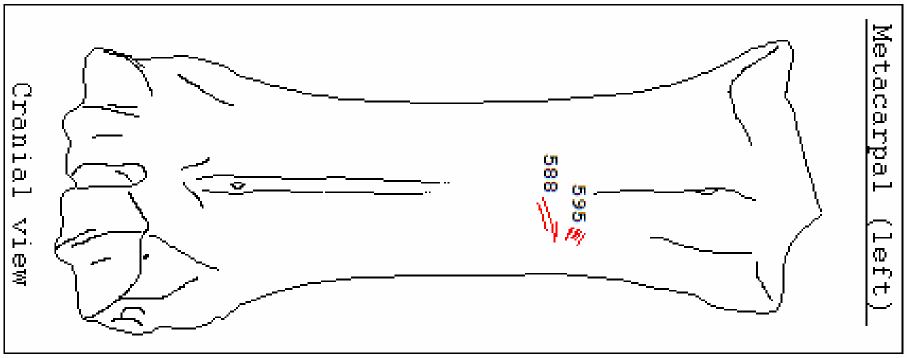

Figure A11. Metacarpal cut mark distribution.

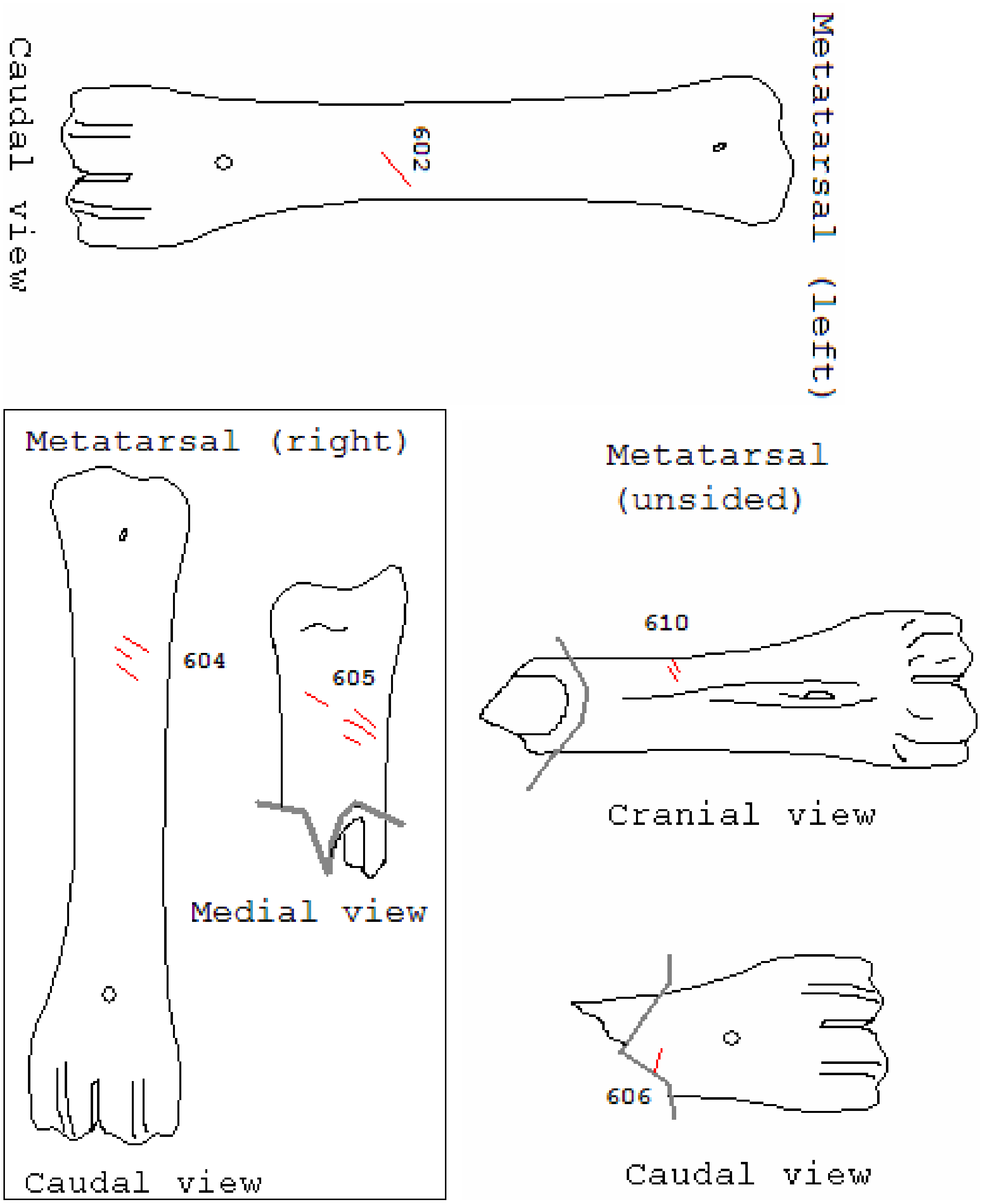

Figure A12. Metatarsal cut mark distribution.

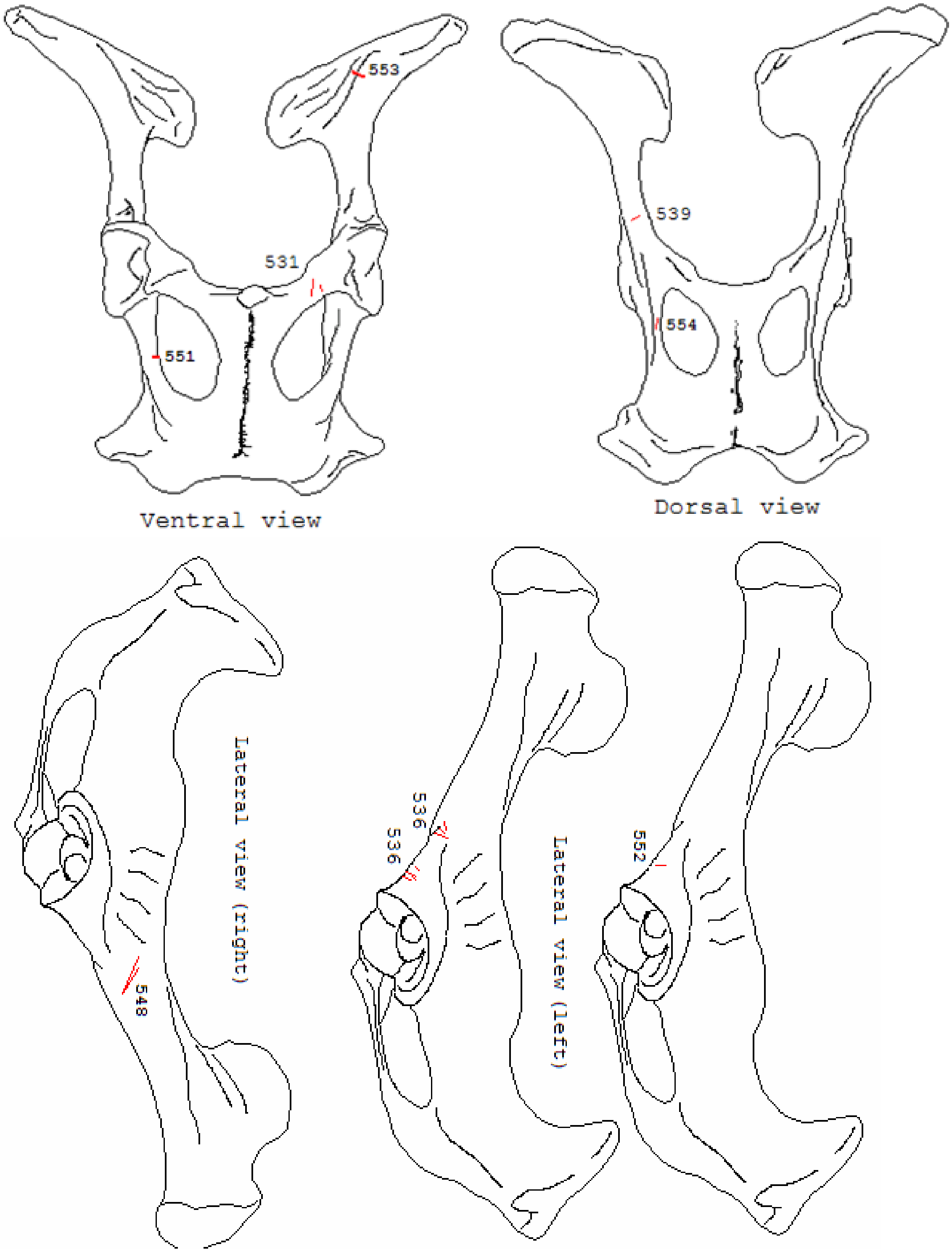

Figure A13. Os coxa cut mark distribution.

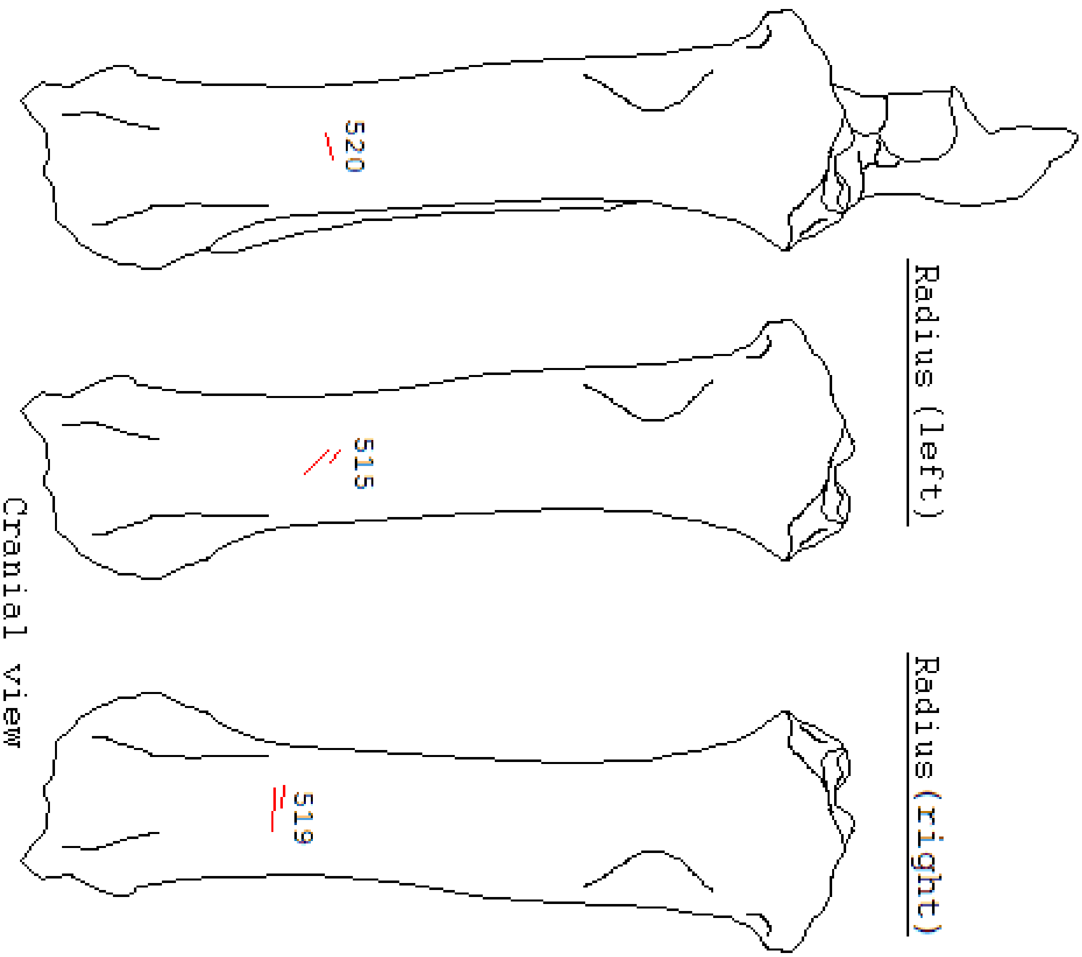

Figure A14. Radius cut mark distribution.

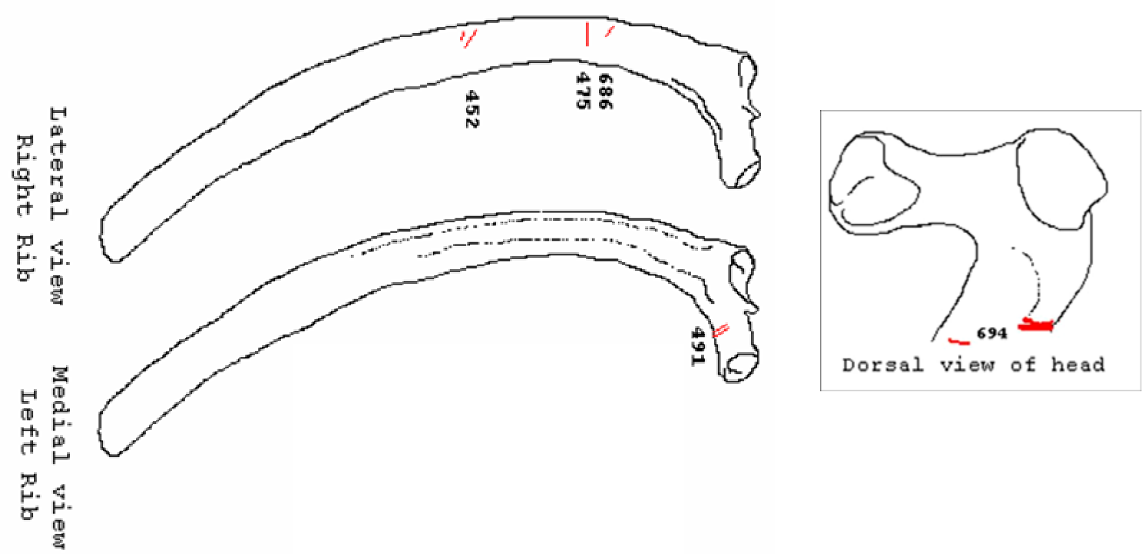

Figure A15. Rib cut mark distribution.

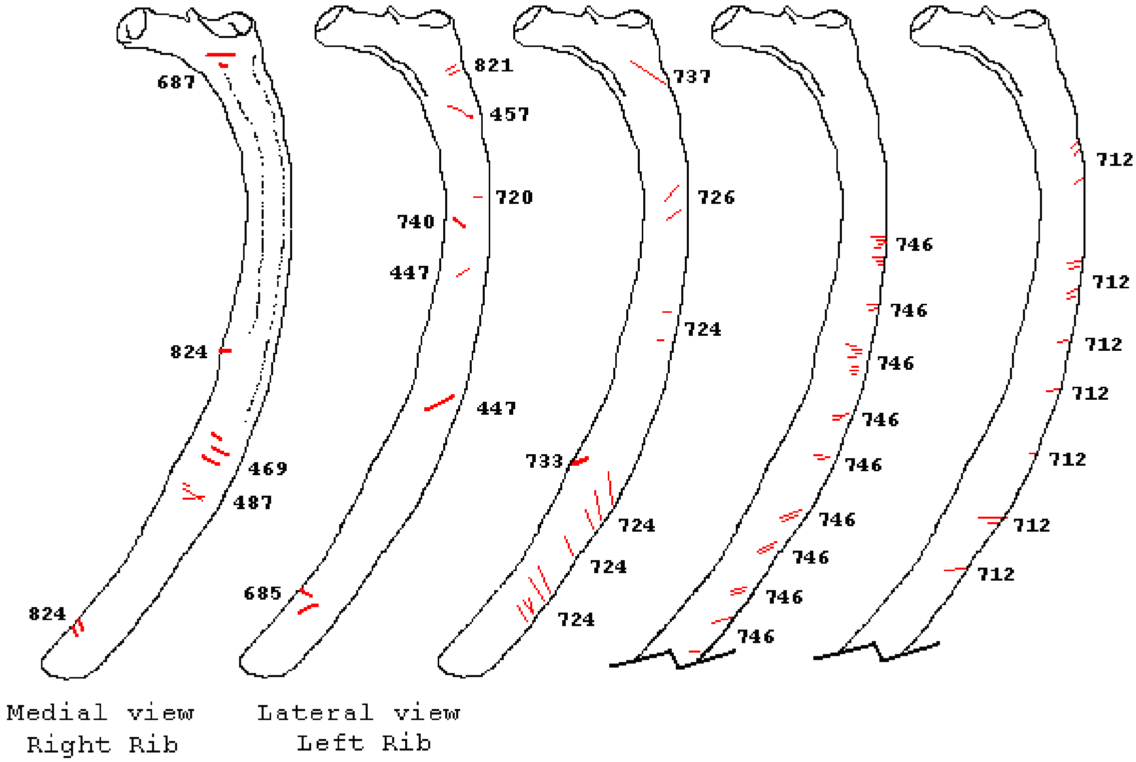

Figure A15 (con't). Rib cut mark distribution.

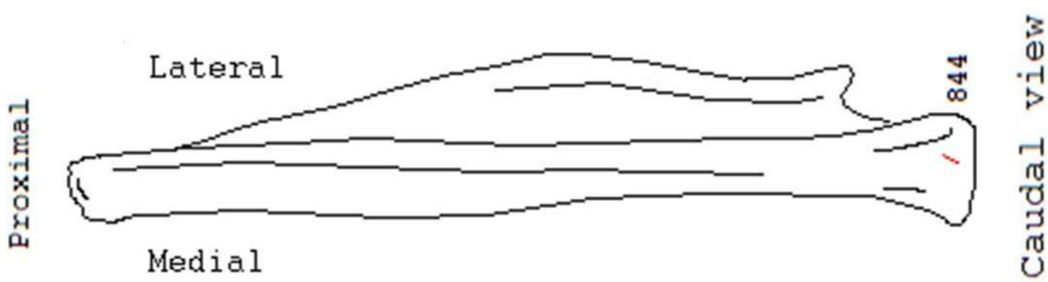

Figure A16. Scapula cut mark distribution.

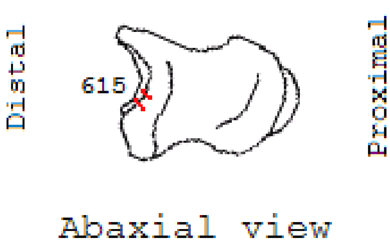

Figure A17. Second phalanx cut mark distribution.

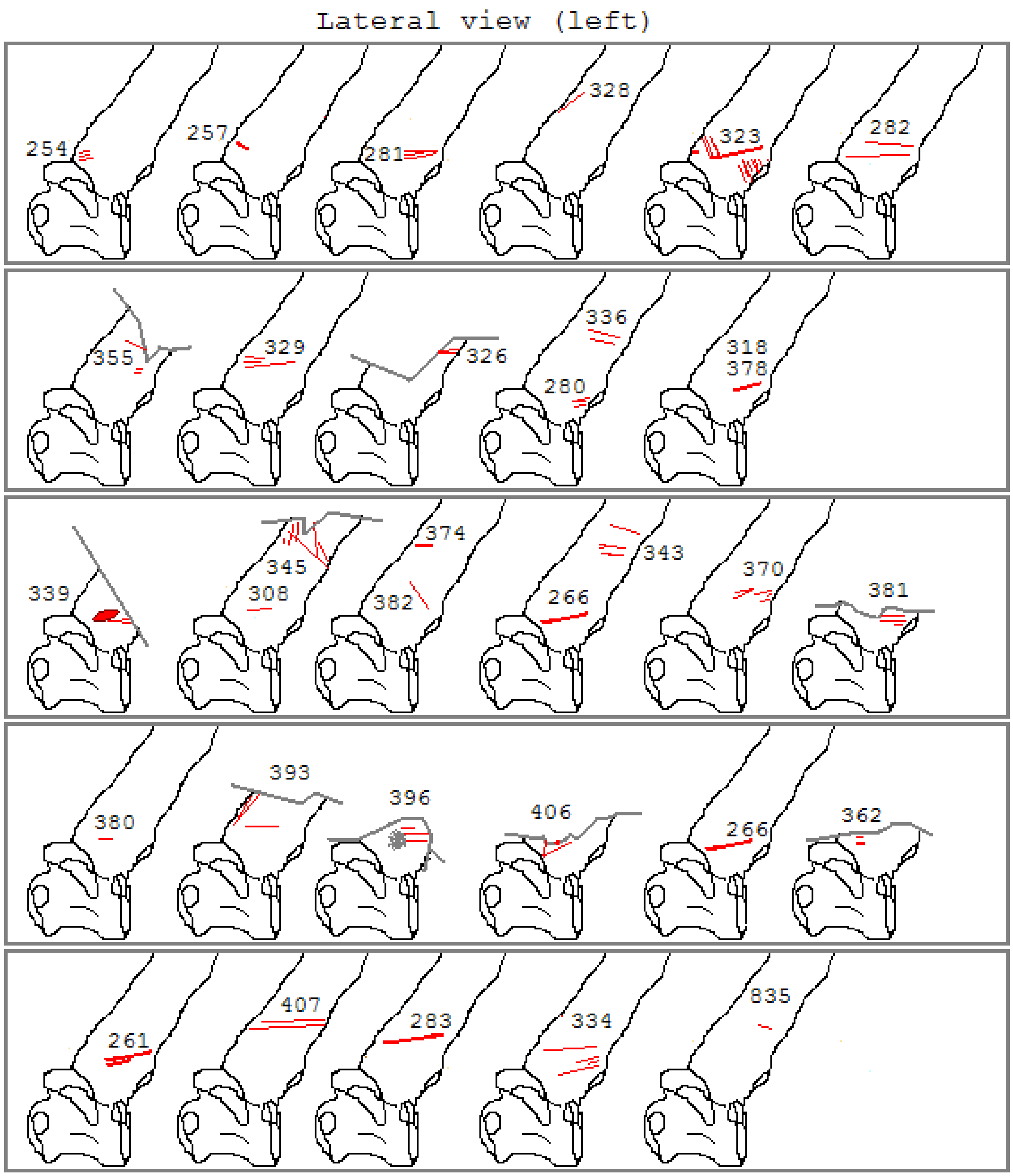

Figure A18. Thoracic vertebra cut mark distribution.

Lateral view (right)

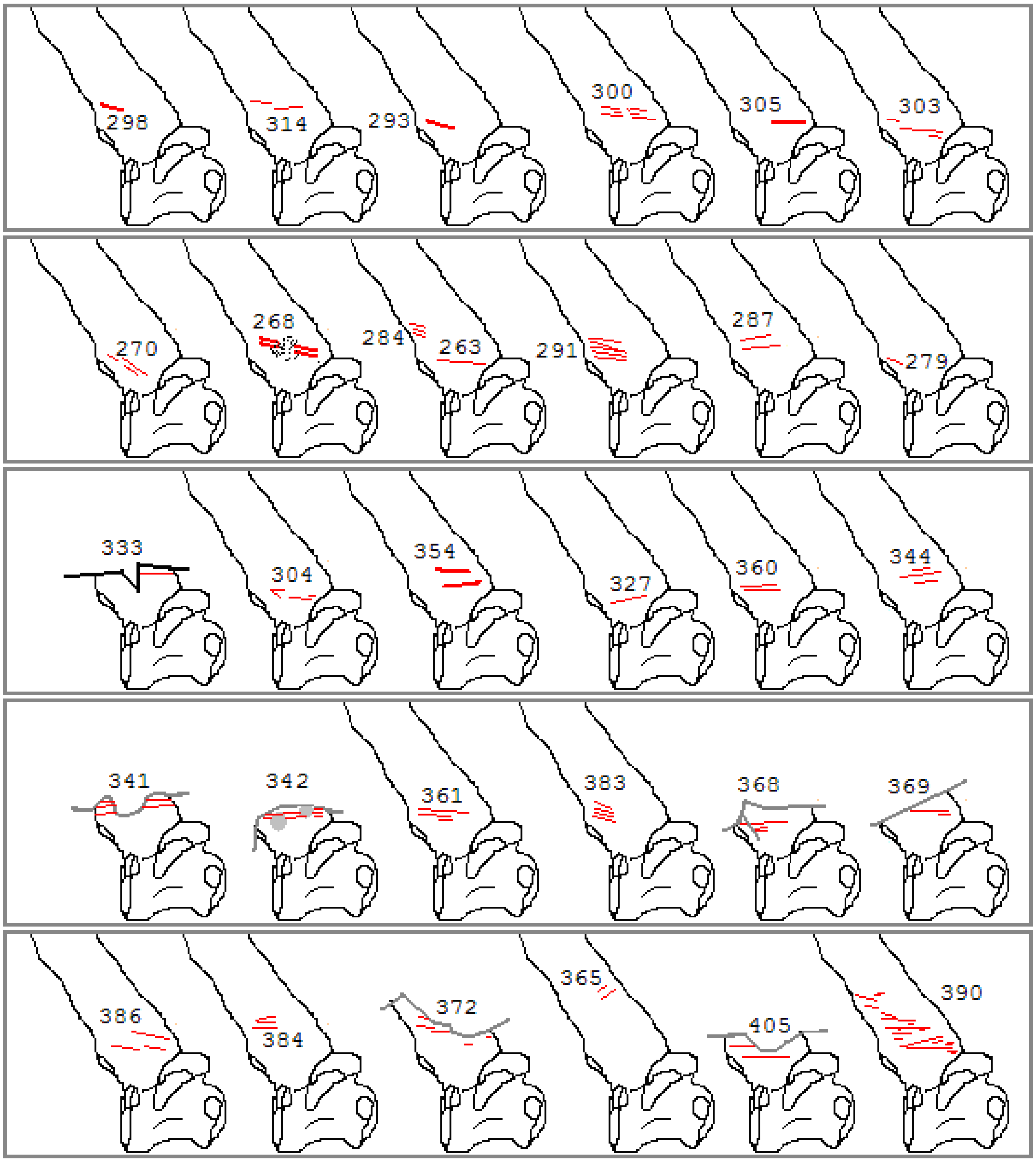

Figure A18 (con't). Thoracic vertebra cut mark distribution

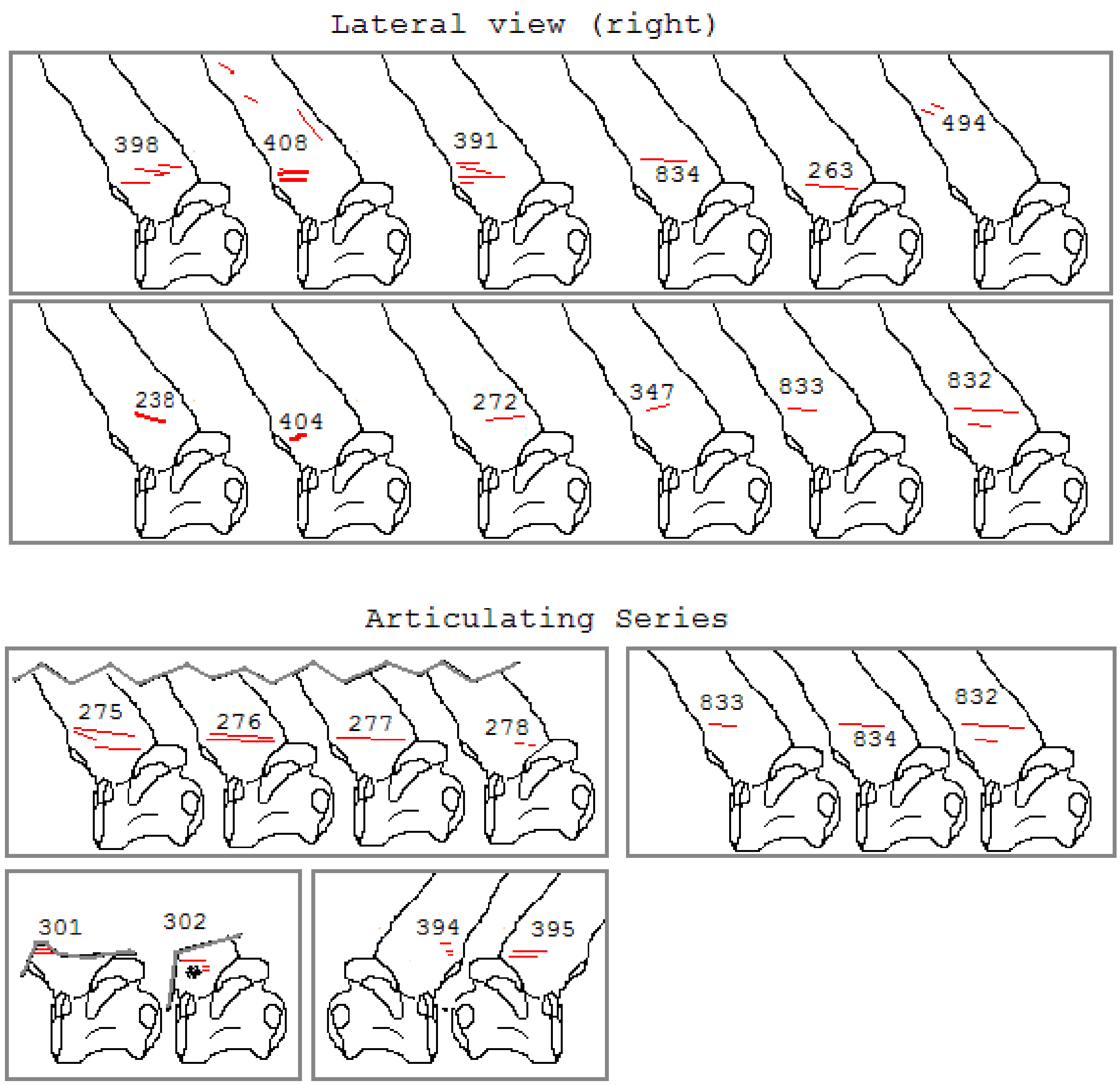

Figure A18 (con't). Thoracic vertebra cut mark distribution

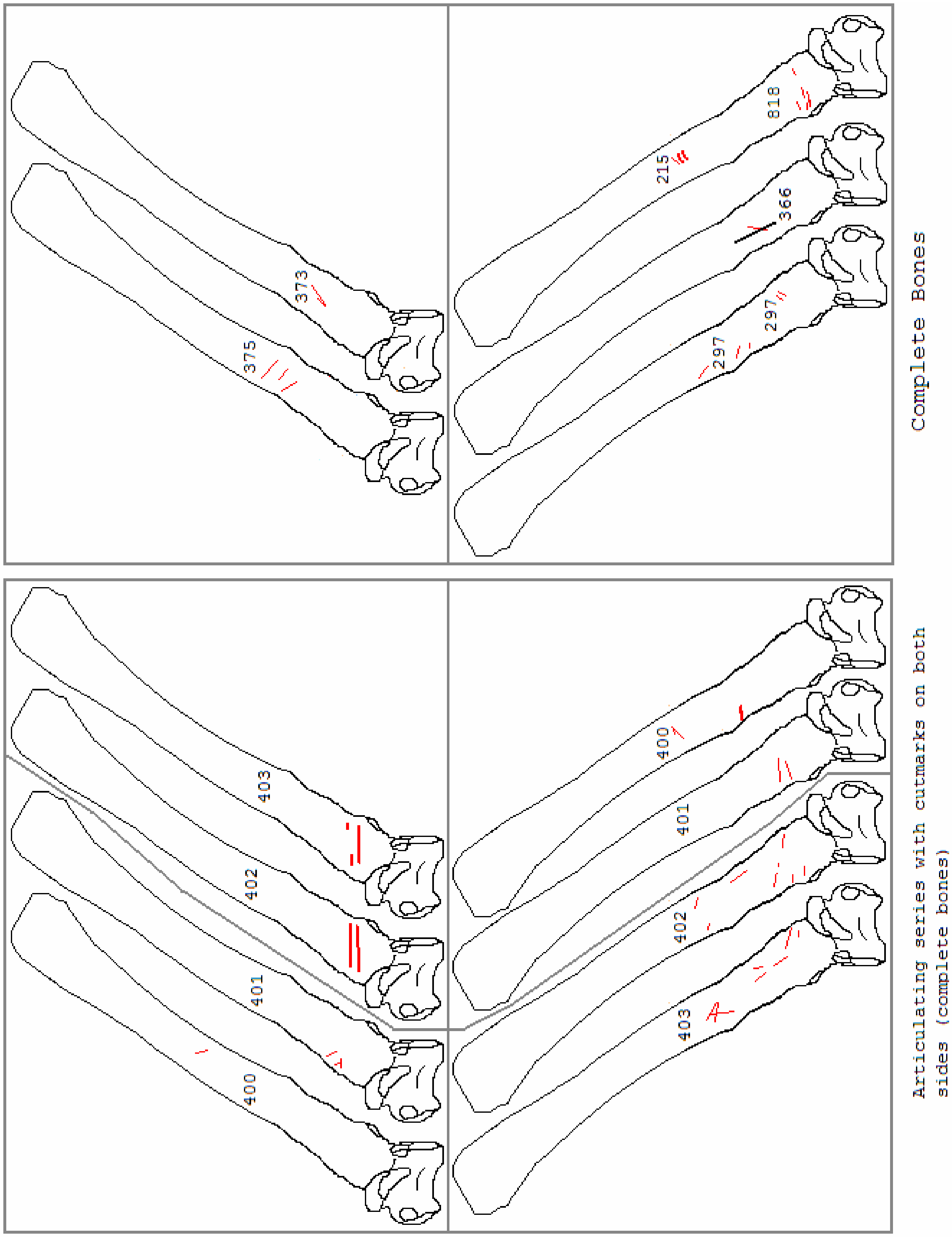

Figure A18 (con't). Thoracic vertebra cut mark distribution

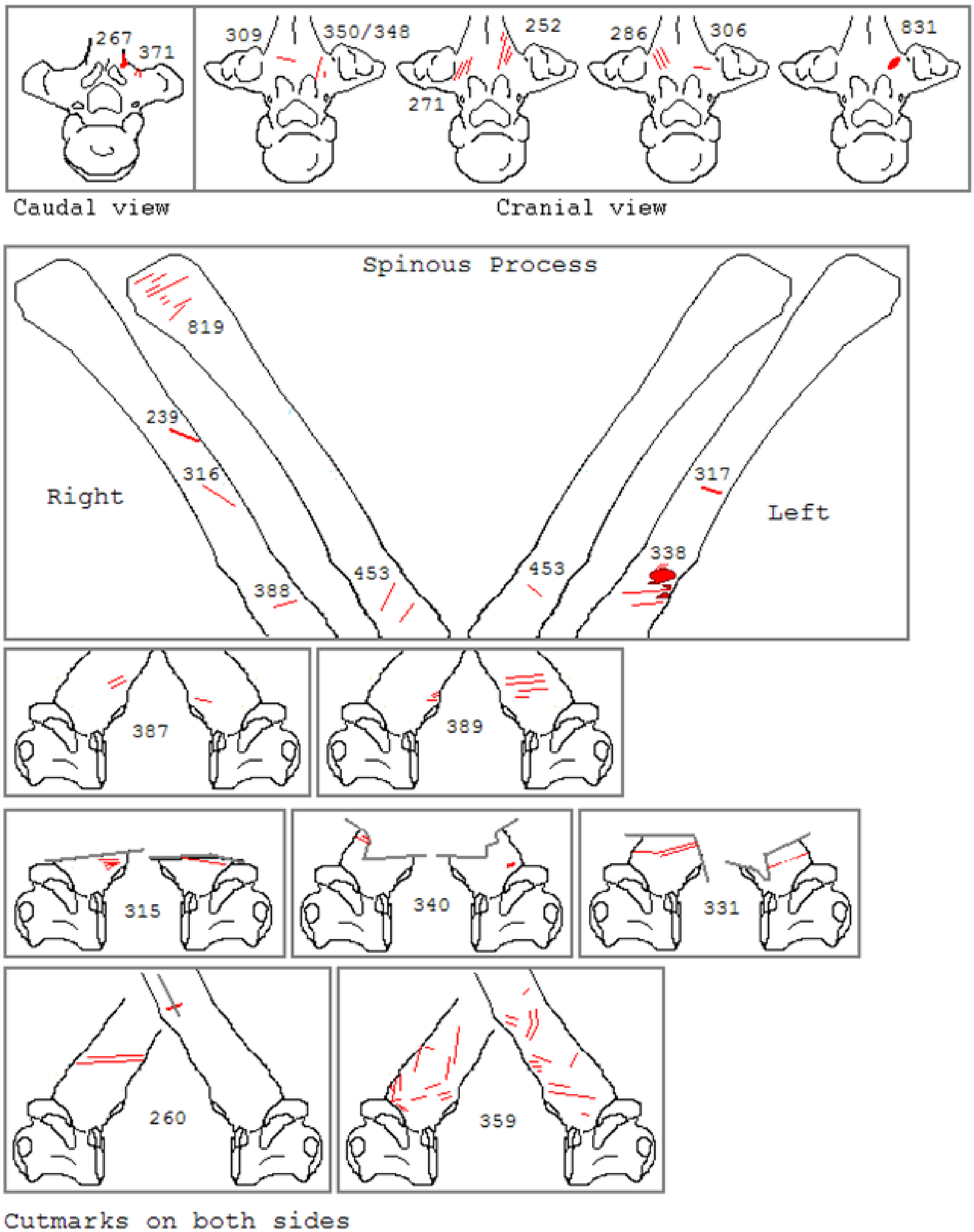

Figure A18 (con’t). Thoracic vertebra cut mark distribution

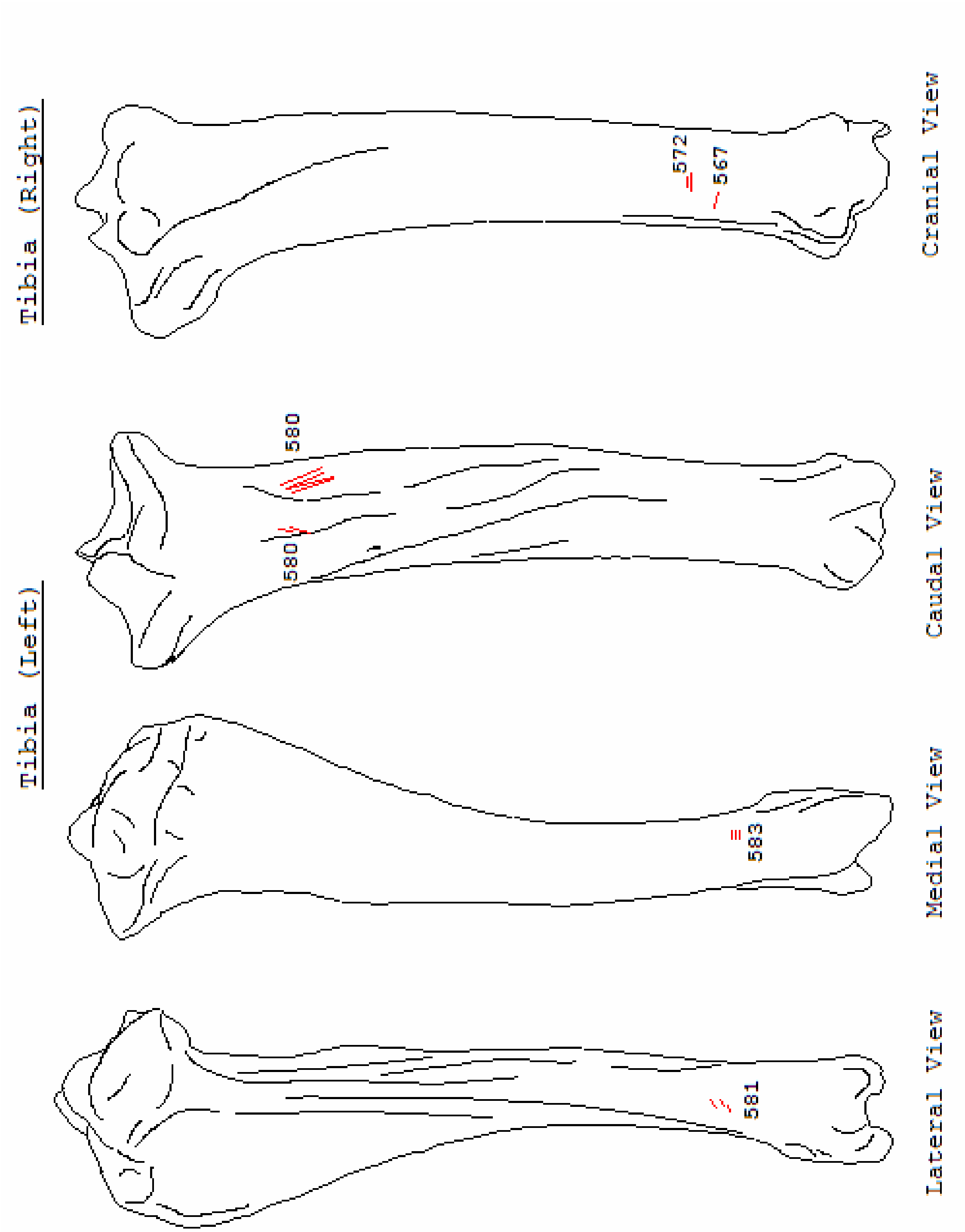

Figure A19. Tibia cut mark distribution.

Appendix B

Experimental Tool Marks

Figure B1. Medial view of unmodified bone (photo taken by Kim Wutzke).

Figure B2. Cranio-lateral view of modified bone showing Sets 1 through 6 (photo taken by Kim Wutzke).

Figure B3. Medial view of bone showing Sets 11 and 12 (photo taken by Kim Wutzke).

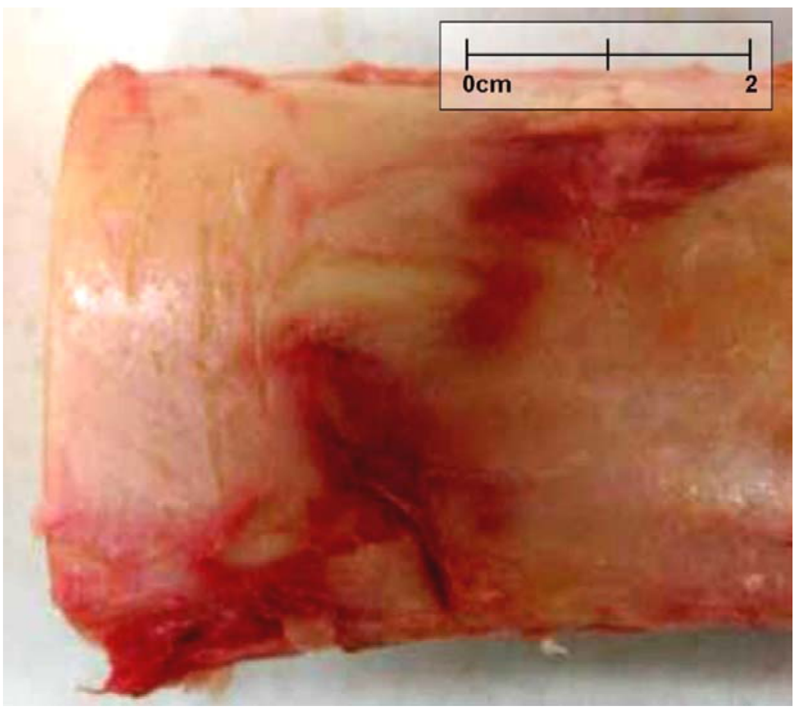

Figure B4. Close-up of Set 1.

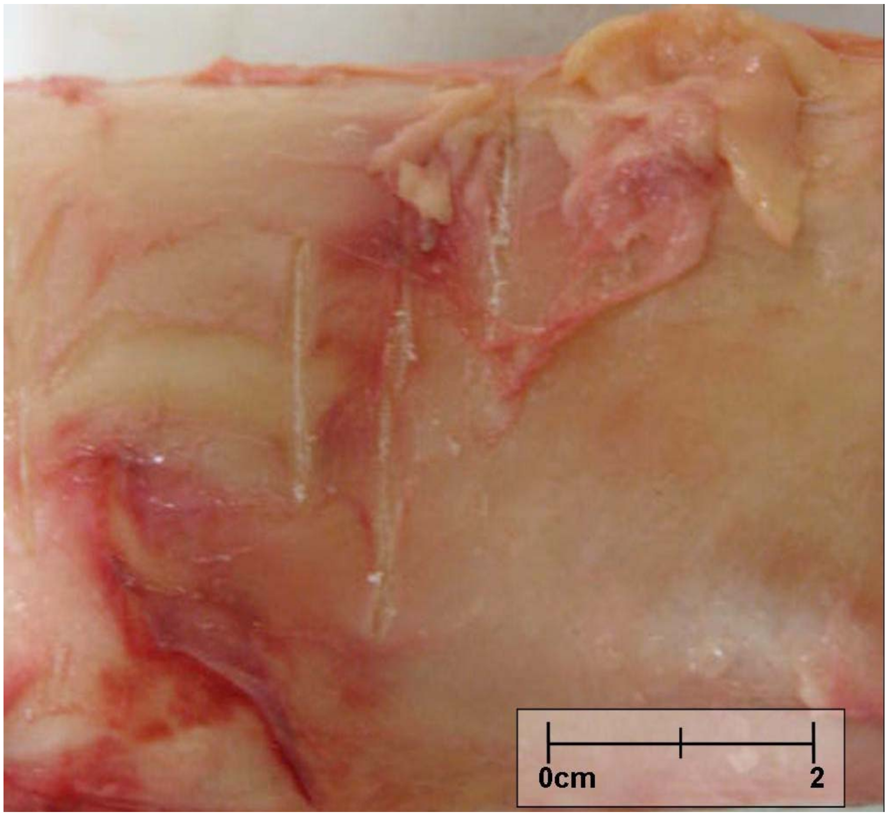

Figure B5. Close-up of Set 2.

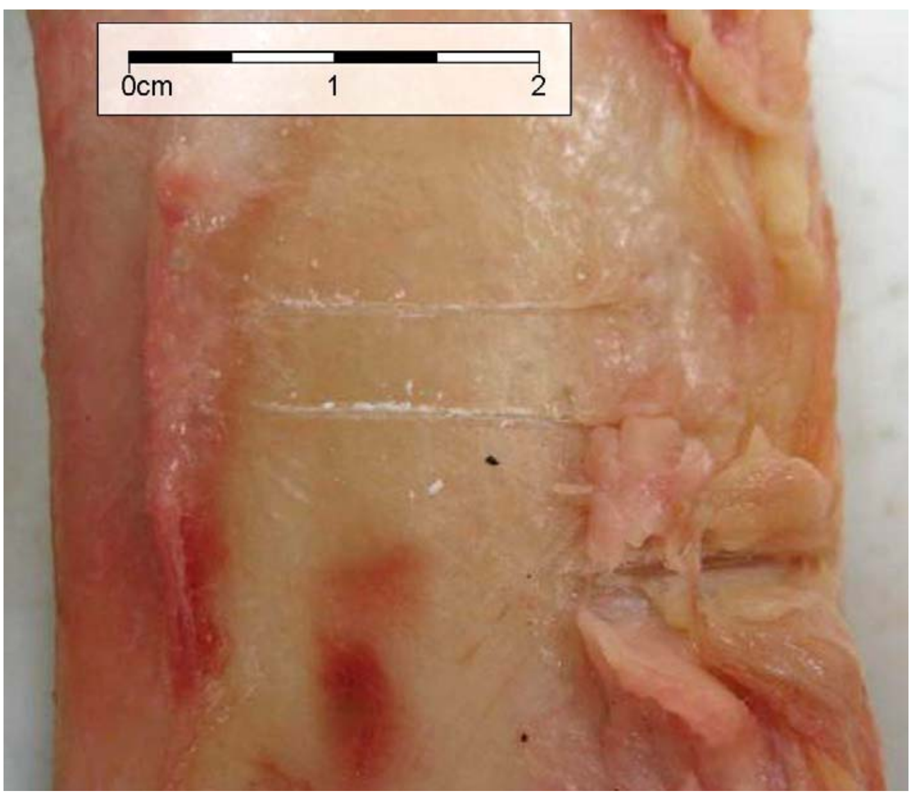

Figure B6. Close-up of Set 3.

Figure B7. Production of Set 4 (photo taken by Kim Wutzke).

Figure B8. Close-up of Set 4.

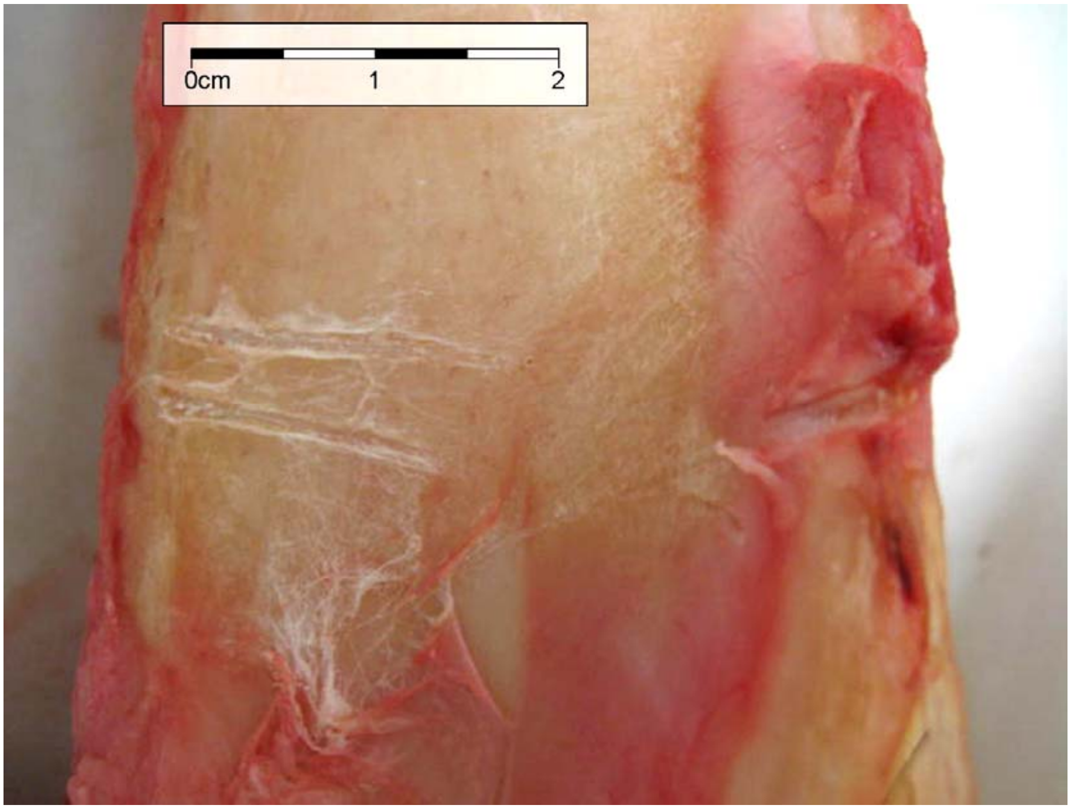

Figure B9. Close-up of Set 5.

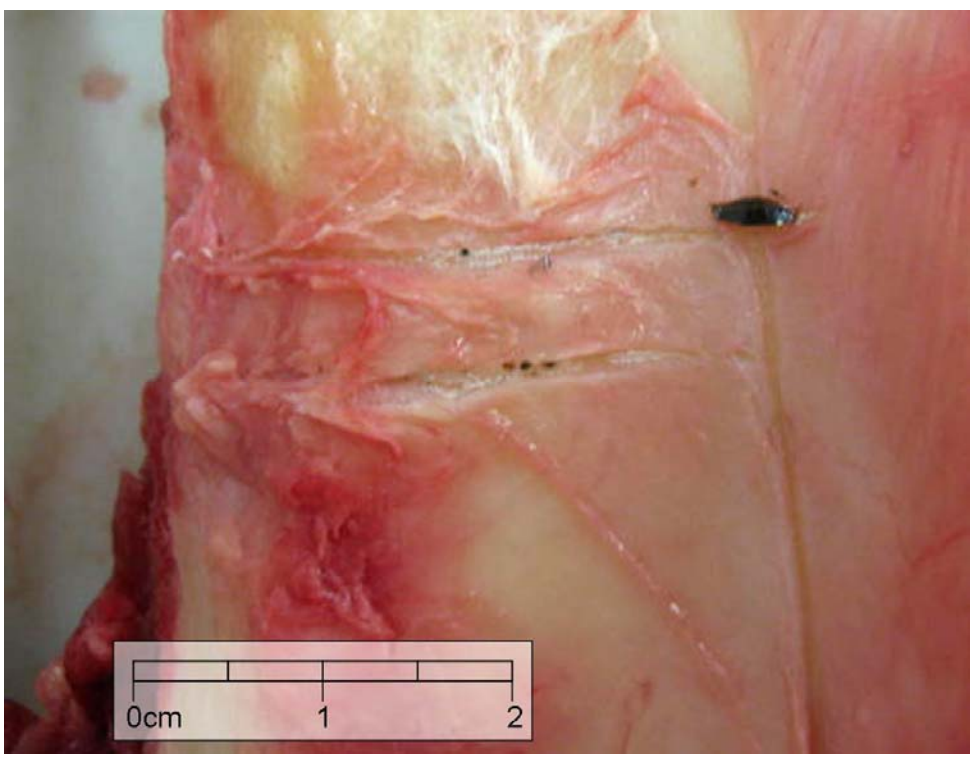

Figure B10. Close-up of Set 6.

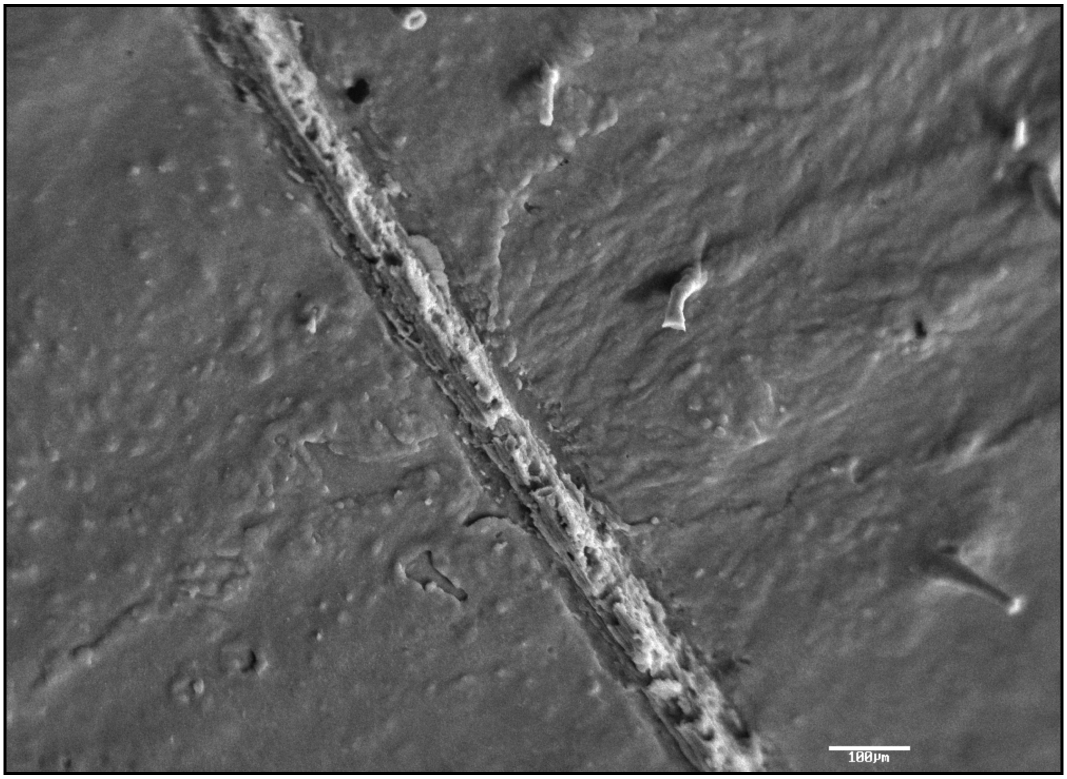

Figure B11. SEM image of Xantopren® mould of Set 1, location 1 (x100 mag.).

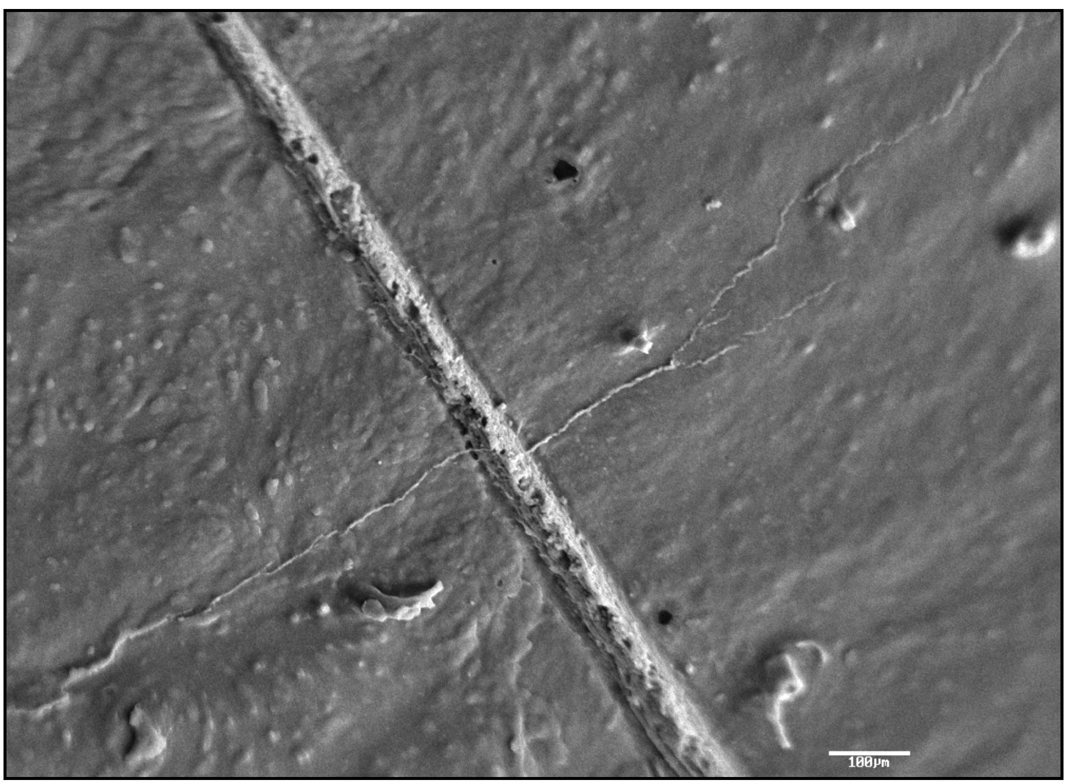

Figure B12. SEM image of Xantopren® mould of Set 1, location 2 (x100 mag.).

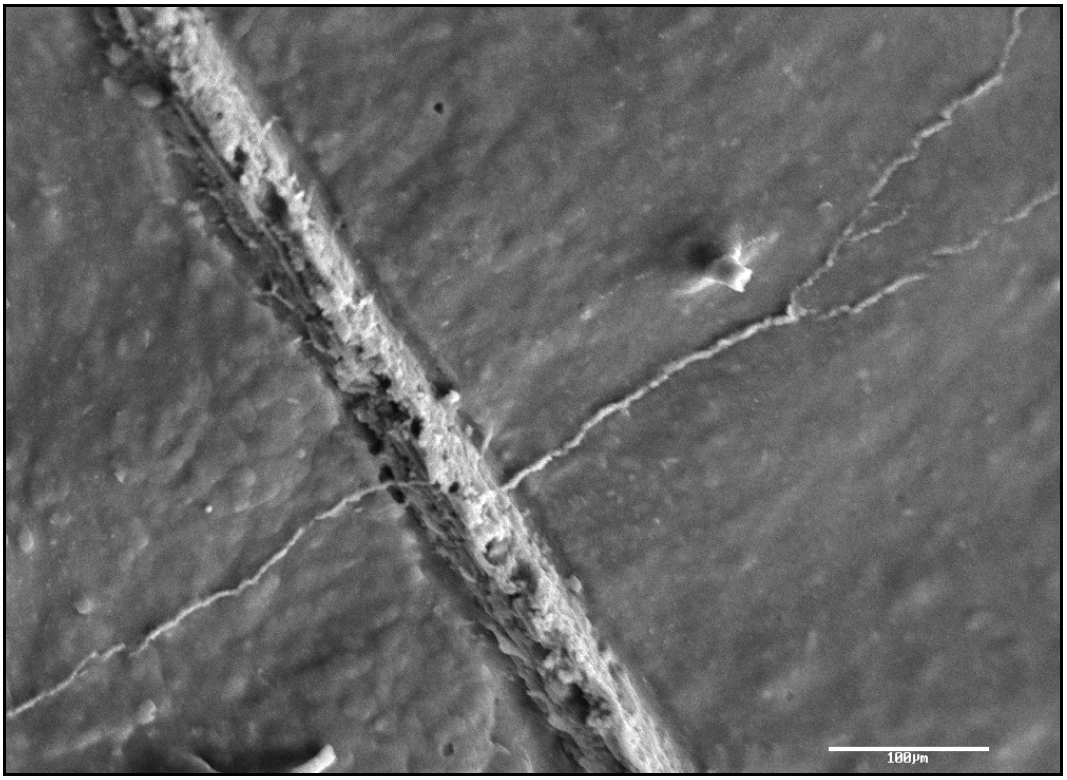

Figure B13. SEM image of Xantopren® mould of Set 1, location 2 (x200 mag.).

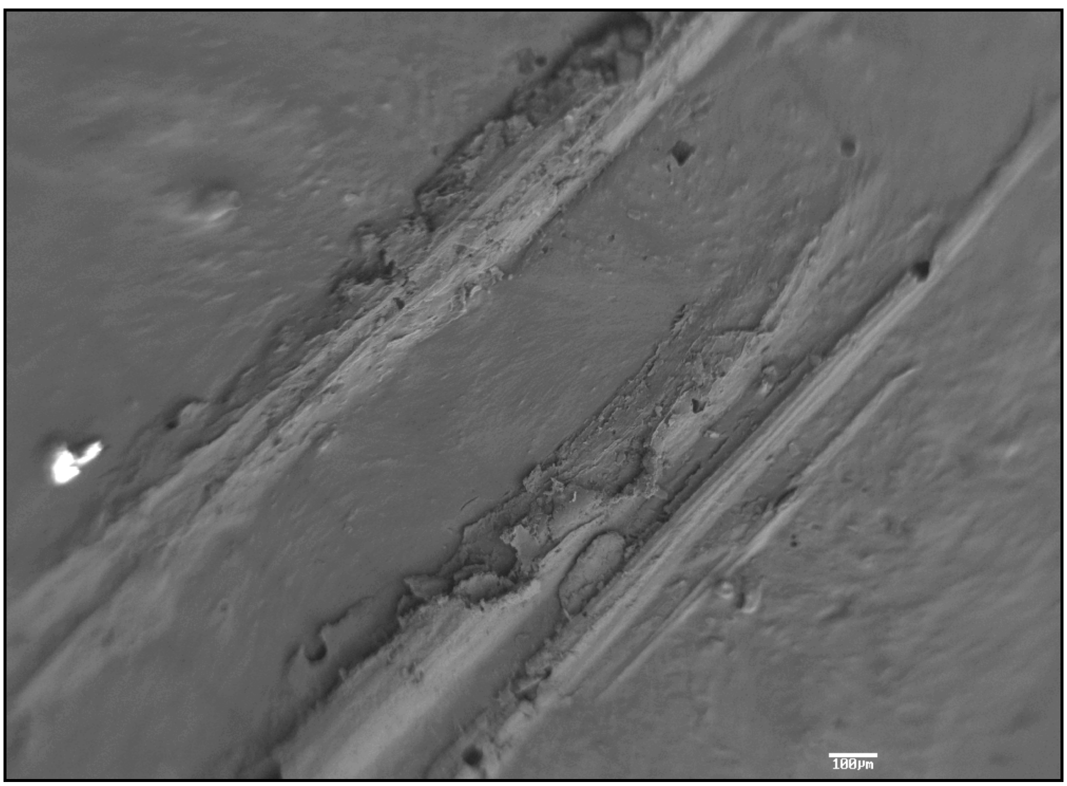

Figure B14. SEM image of Xantopren® mould of Set 2, location 1 (x60 mag.).

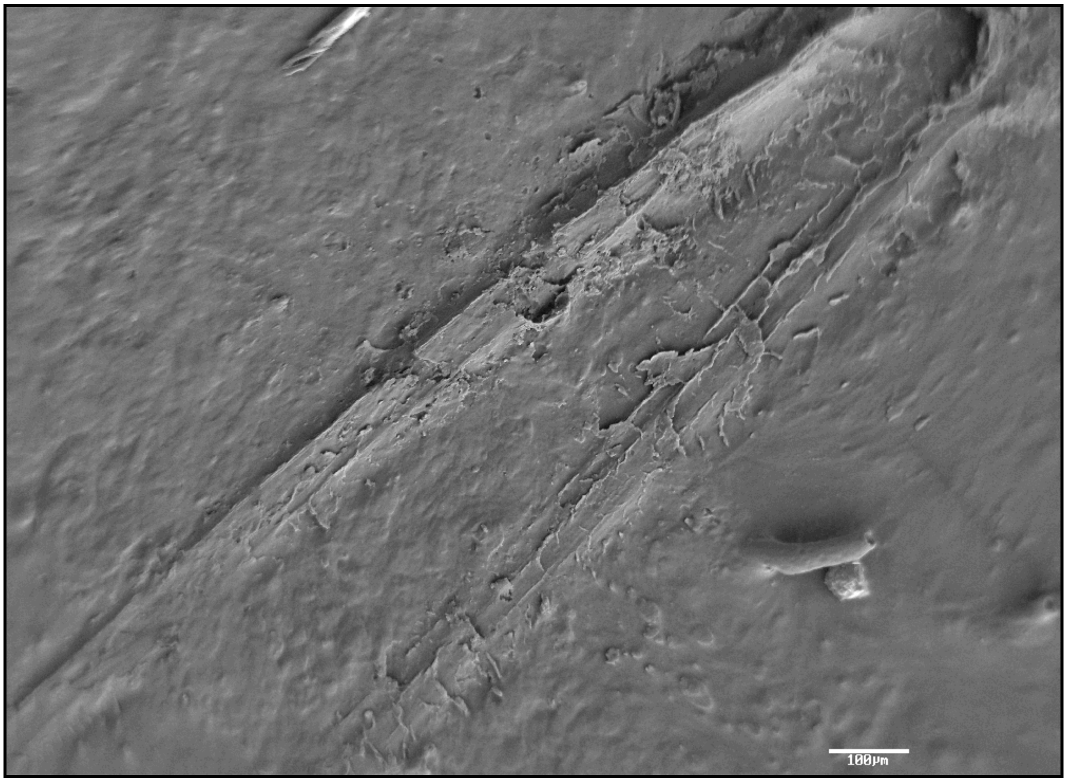

Figure B15. SEM image of Xantopren® mould of Set 2, location 3 (x100 mag.).

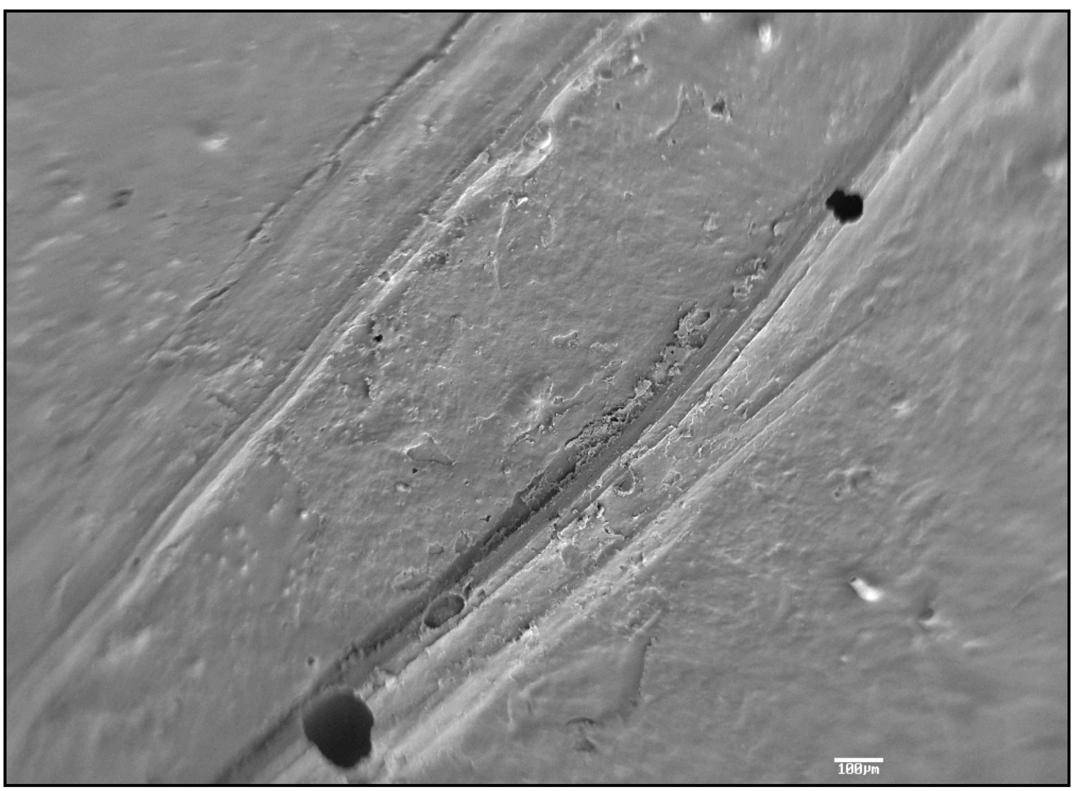

Figure B16. SEM image of Xantopren® mould of Set 2, location 3 (x60 mag.).

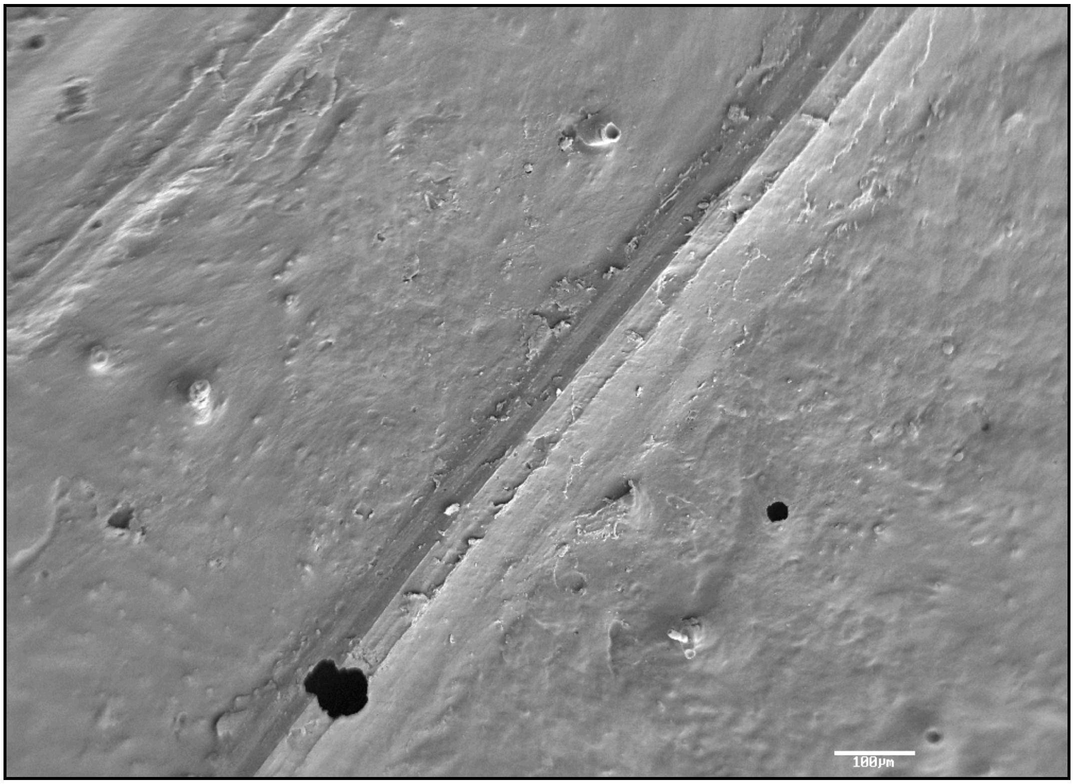

Figure B17. SEM image of Xantopren® mould of Set 2, location 3 (x100 mag.).

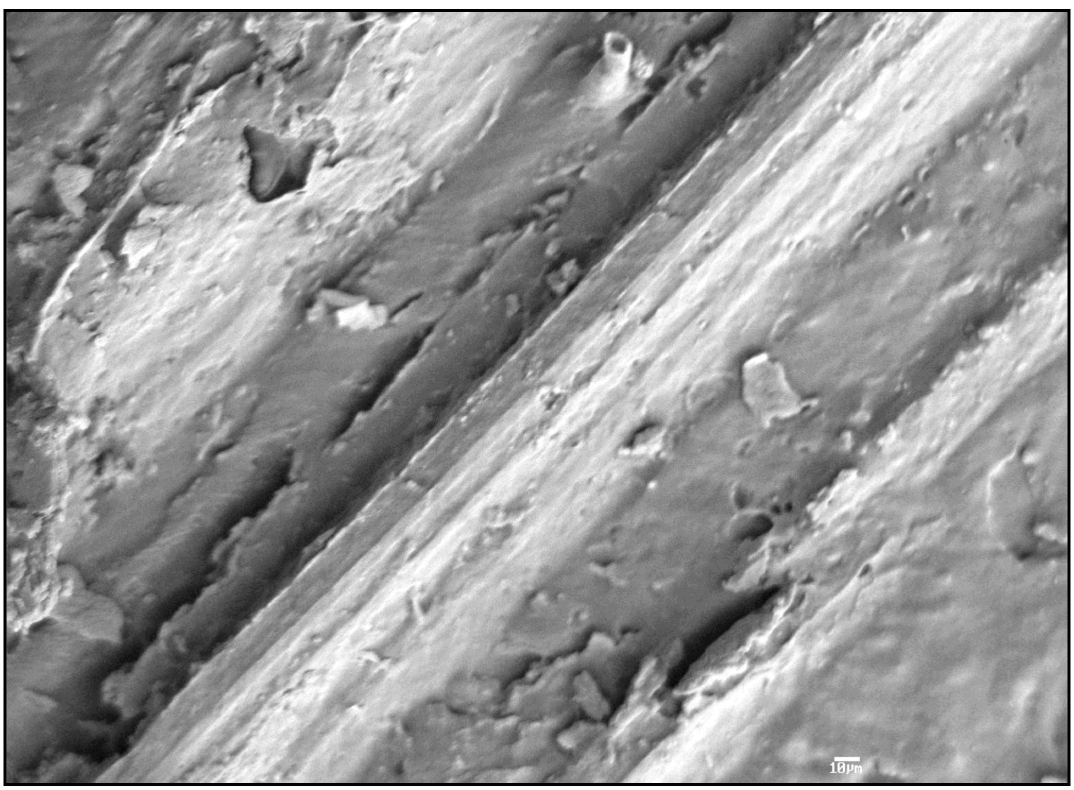

Figure B18. SEM image of Xantopren® mould of Set 2, location 3 (x300 mag.).

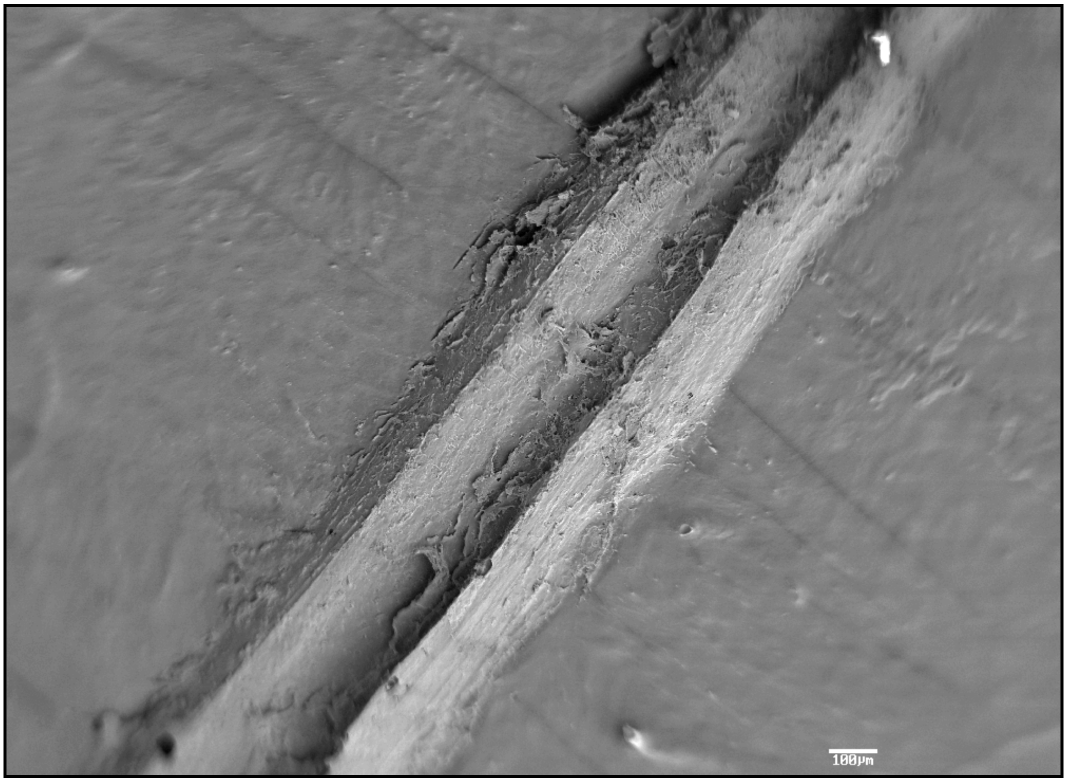

Figure B19. SEM image of Xantopren® mould of Set 3 (x60 mag.).

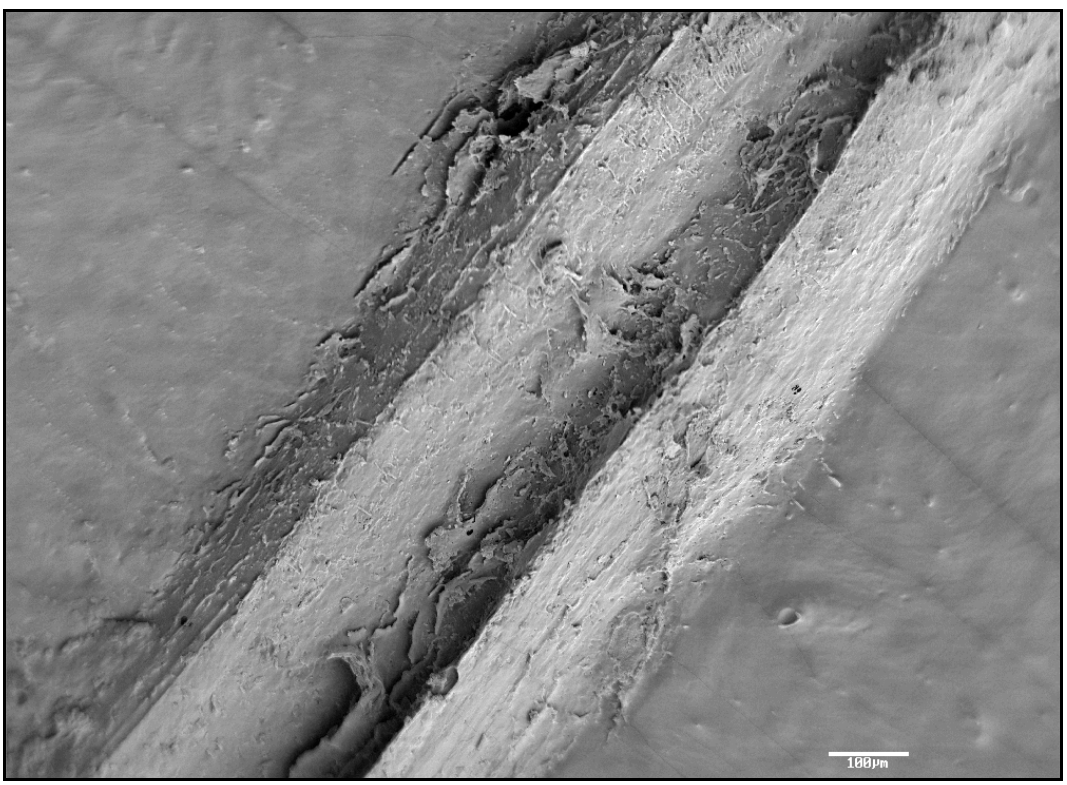

Figure B20. SEM image of Xantopren® mould of Set 3 (x100 mag.).

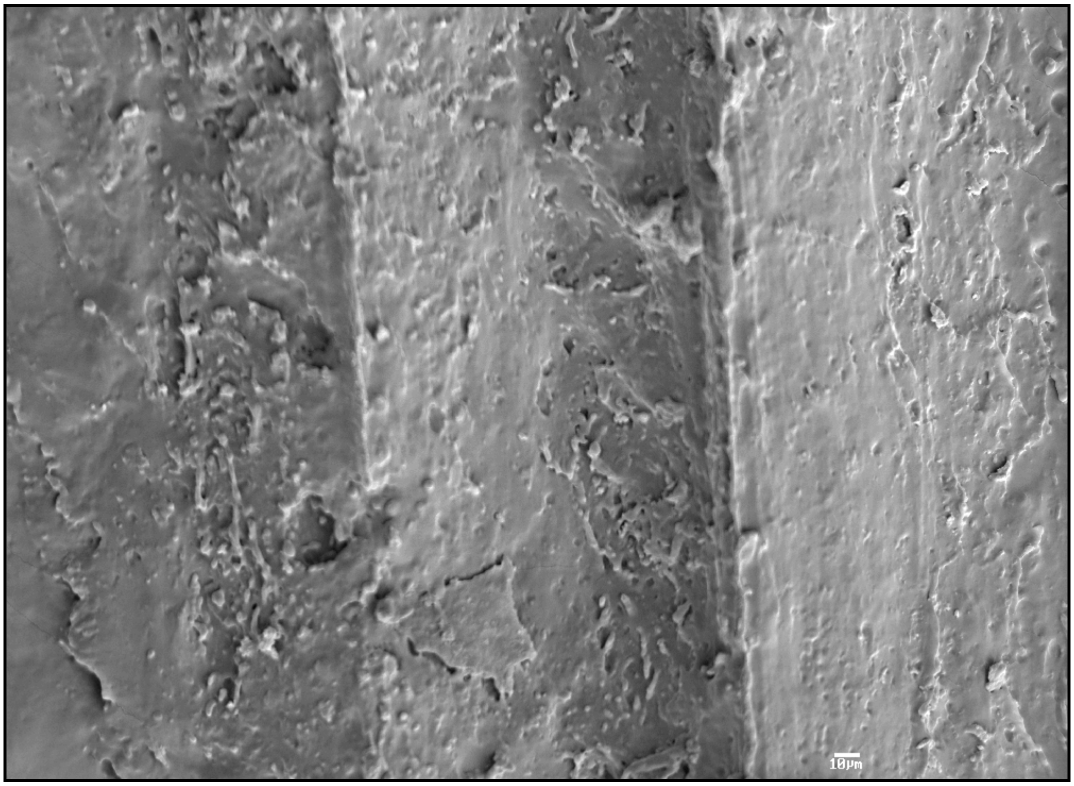

Figure B21. SEM image of Xantopren® mould of Set 3 (x300 mag.).

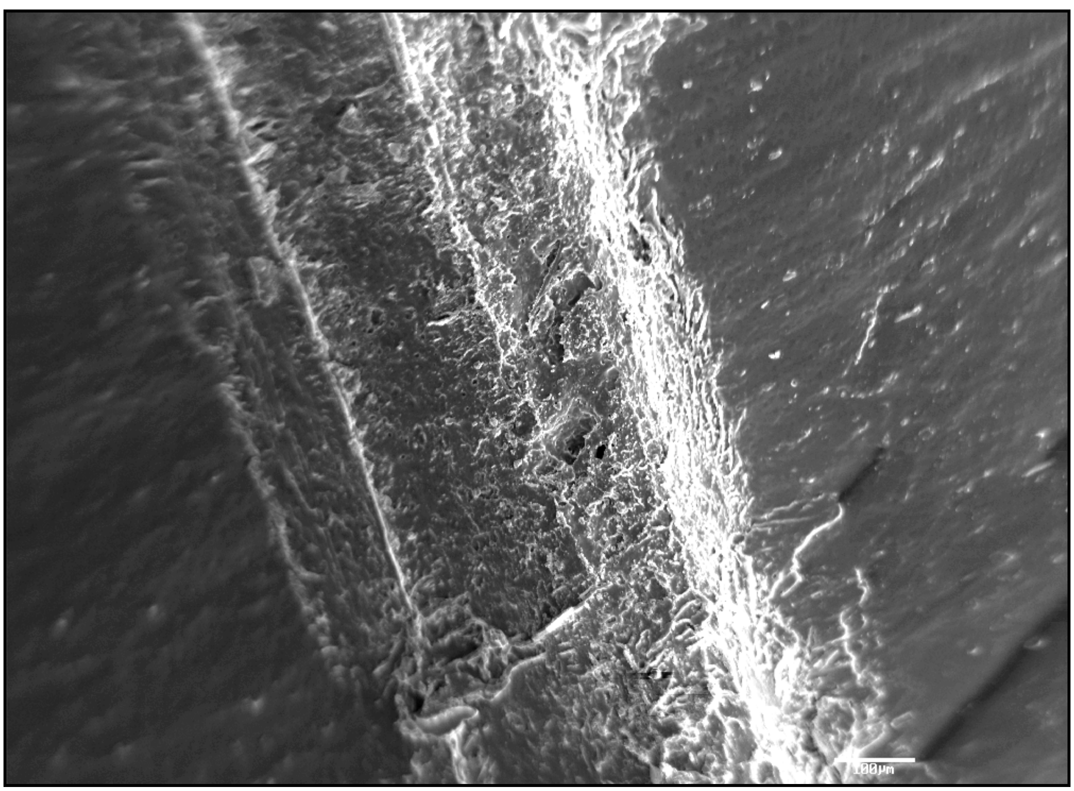

Figure B22. SEM image of Xantopren® mould of Set 3 (x100 mag.).

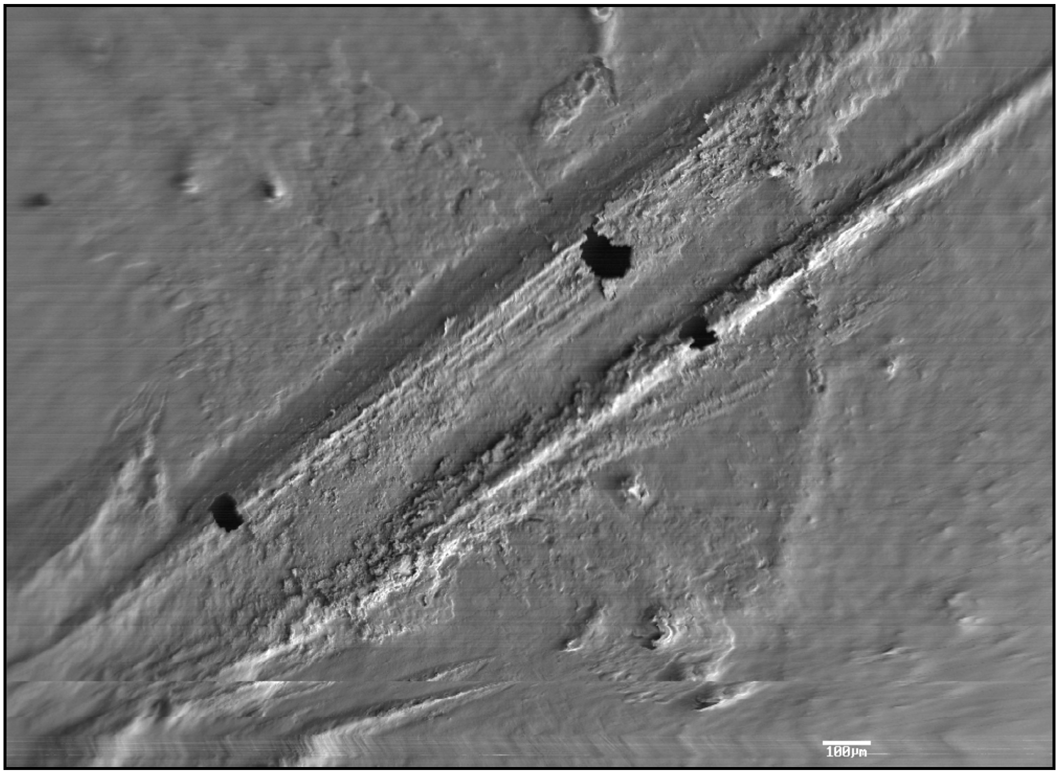

Figure B23. SEM image of Xantopren® mould of Set 4 (x60 mag.) showing charging and air bubbles.

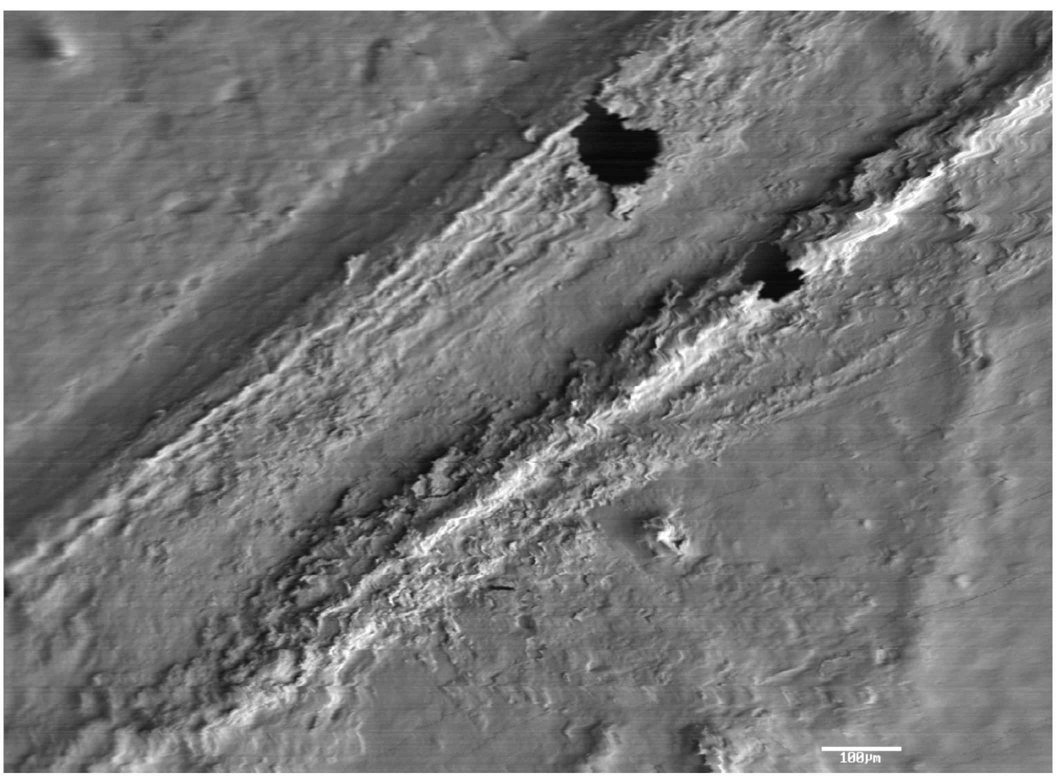

Figure B24. SEM image of Xantopren® mould of Set 4 (x100 mag.) showing charging and air bubbles.

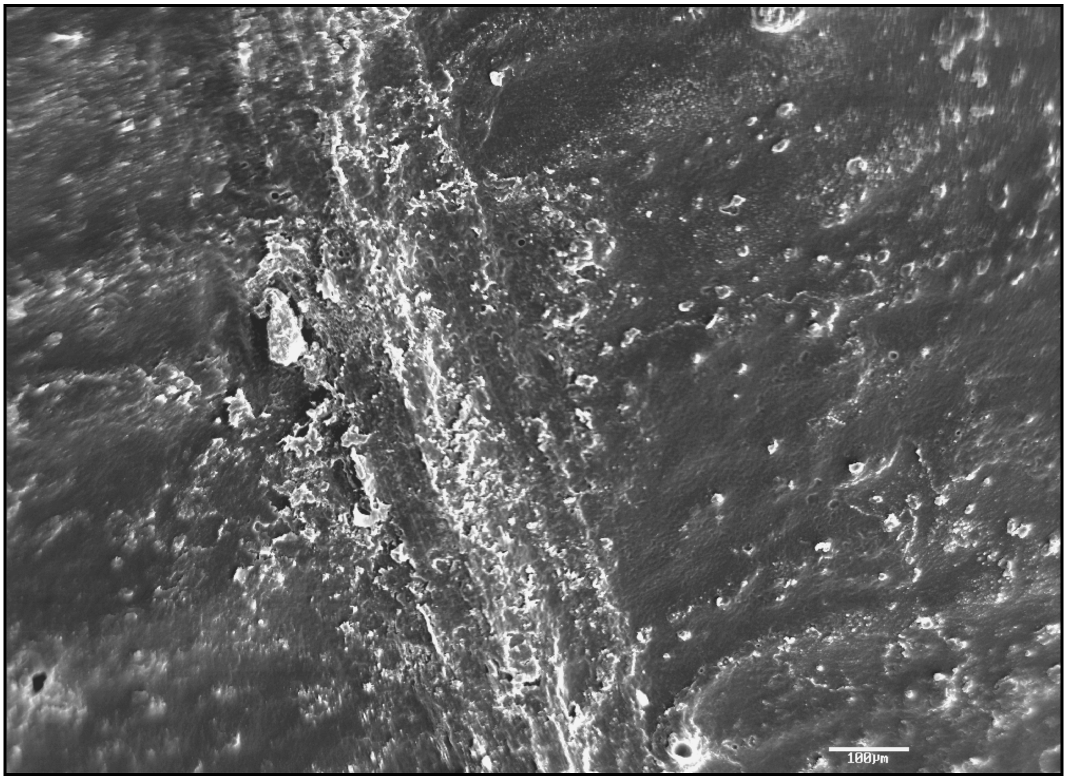

Figure B25. SEM image of Xantopren® mould of Set 5 (x100 mag.).

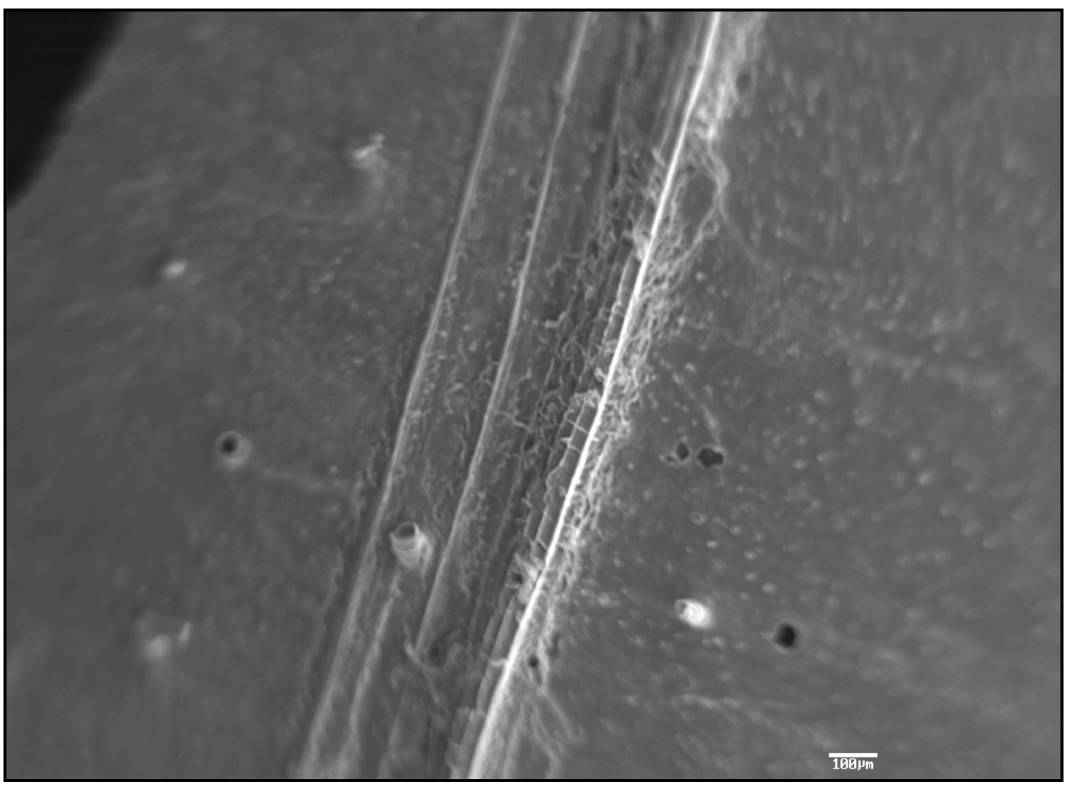

Figure B26. SEM image of Xantopren® mould of Set 6, location 1 (x60 mag.).

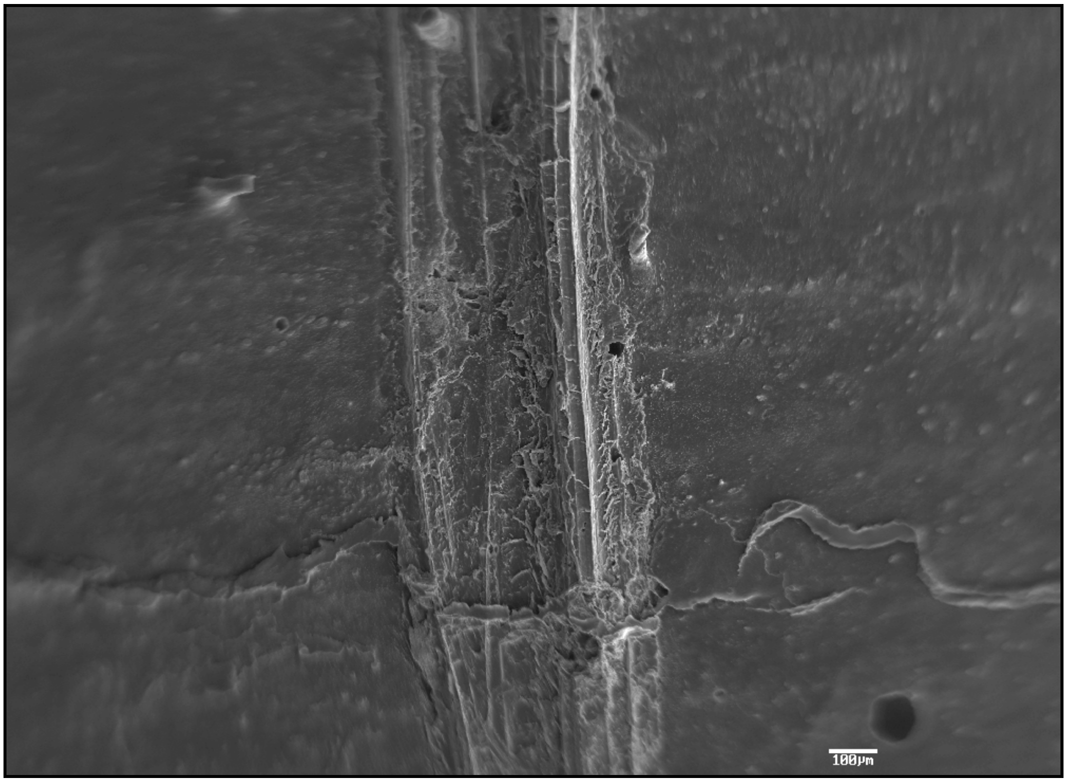

Figure B27. SEM image of Xantopren® mould of Set 6, location 2 (x60 mag.).

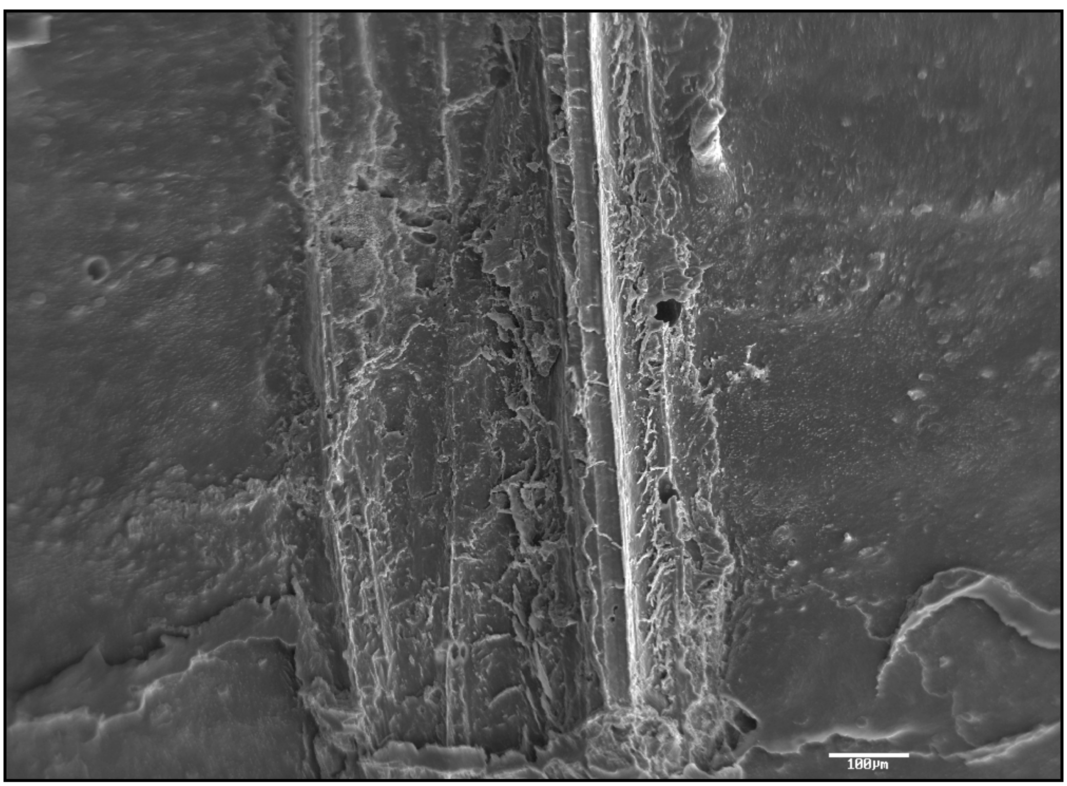

Figure B28. SEM image of Xantopren® mould of Set 6, location 2 (x100 mag.).

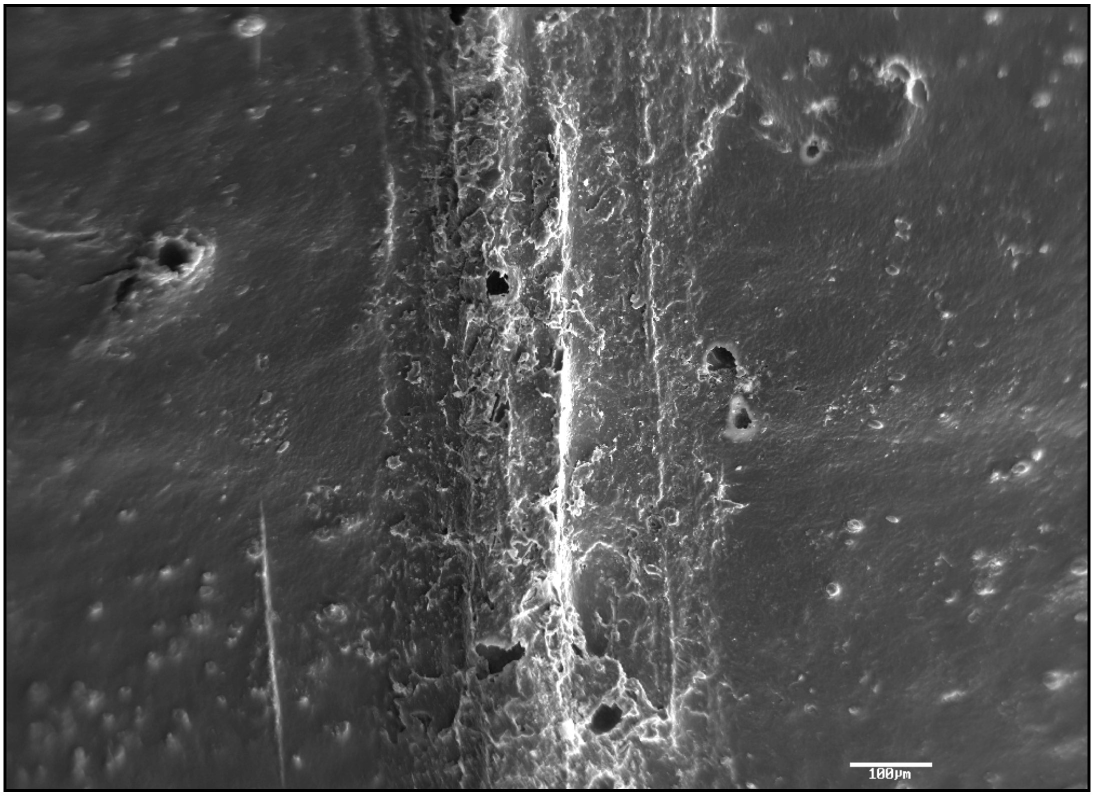

Figure B29. SEM image of Xantopren® mould of Set 6, location 3 (x100 mag.).

Appendix C

Comparison of Mould Materials

Jeltrate® Plus is a dustless alginate-based impression material. This material was selected for the first trial because it is a very common dental mould-making material and, as such, was readily available, inexpensive, and required no additional application apparatus (Table C1).

Table C1. Features of Moulding Materials

Brand Name	**Jeltrate® Plus**	**Xantopren® Comfort Light**
Description	Powder based, alginate impression material	Liquid based, polysiloxane
Cost	Low	High
Accessibility	Easily acquired	Harder to acquire
Preparation and Application	8g powder per 19ml water, mixed thoroughly (1 minute), applied with a spatula	2-component material comprising base paste and matching catalyst paste combined in 4:1 ratio with dispensing gun
Set Time	4 minutes (including 60 second mixing time and 2.5 minute maximum manipulation time)	5-6 minutes
Reliability	Unreliable - high surface adhesiveness yields high failure rate	Reliable - low surface adhesiveness yields lower failure rate
Warping	Medium to high (varies with size)	Less than 1% warping over time; not water based so does not desiccate
Initial Viscosity	Low (varies with quantity of water)	Low
Elasticity (after setting)	Flexible when set while still wet, hardens and warps when desiccated	Becomes solid when set but maintains flexibility over time
SEM	Large grain size and porosity; useful at low magnifications (less than x80)	No grains; no magnification limit

While Jeltrate® was a convenient mould material to use, several difficulties revealed it to be an unacceptable material for the required purpose. During the moulding process, moulds were prone to damage and breakage while being removed from the bone. The accuracy of the mould was susceptible to slight differences in amount of water used in preparation. A slightly greater amount of water than suggested in the package instructions was more favourable, but an exact optimal ratio was never determined (Table C1). Moulds were subject to warping during drying, especially in relatively large moulds, which would sometimes crease the mould.

Most importantly, microscopically, the particle size proved to be larger than is required for fine detail (Figures C1 and C2). This was indicated in an analysis of the dry powder by SEM technician Thomas Bonli (personal communication, Jan 17, 2007) who noted that “the finest grains are around 20 to 40 μm” suggesting that “features less than about 25 to 50 um” will not be detailed if this material was used to mould them. This is a problem considering that many of the finer cut marks are on this scale.

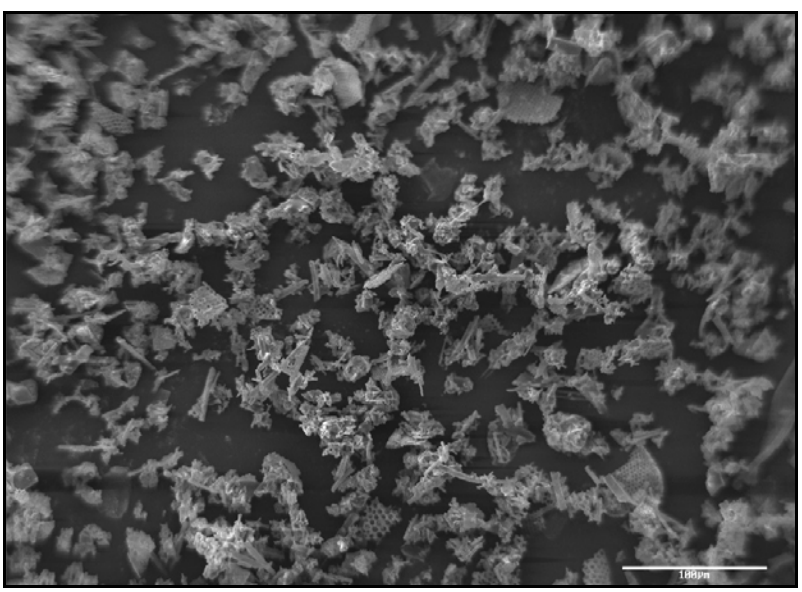

Figure C1. SEM image of Jeltrate® dry powder grains (Tom Bonli, personal communication, Jan 17, 2007).

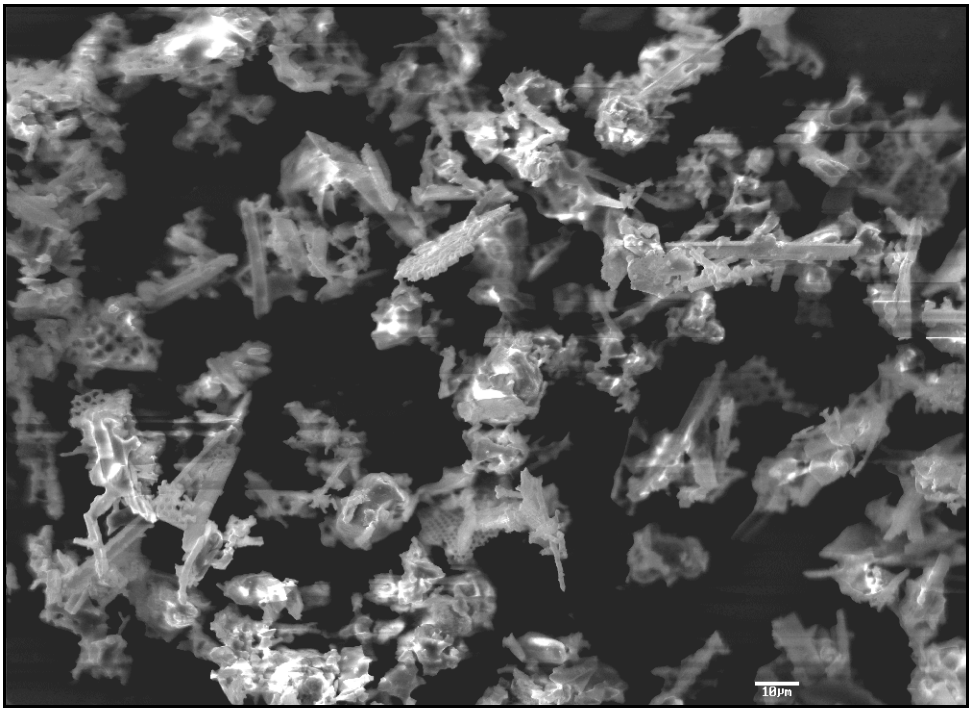

Figure C2. SEM image of Jeltrate® dry powder grains at high magnification (Tom Bonli, personal communication, Jan 17, 2007).

Since Jeltrate® was found to be unsuitable for the current research and so a second trial was conducted. Xantopren® Comfort Light polysiloxane (polymerized siloxane) impression material was employed in the second trial. It is a common substance used in forensic evidence collection and is considered excellent for laboratory work. Comparative studies have ranked this substance as the relative best in categories of “detail reproduction”, “deep angles application”, and least likely to “develop air bubbles and other imperfections” (Du Pasquier et al. 1996:40).

Xantopren® was recommended by comparative microscopy studies of mould making materials for use in SEM analysis (Scott 1982) and was also recommended by Rose (1983:257) as a useful moulding material for archaeological SEM studies as it meets her major criteria of accuracy in copying, ease of removal, good shelf life, and ease of preparation and application. Other studies have used similar materials such as

“Exaflex” (Bromage 1987; Gibert and Jimenez 1991), “Coe-flex” (Walker and Long 1977), Coltene brand Rapid Liner (Pickering and Wallis 1997), Ventura Toplight© silicone based impression material and epoxy moulds (Domínguez-Rodrigo et al. 2005), or Dow Corning Silastic 9161 molding compound with Cutter Perfourm Light Vinyl Polysiloxane Impression Material (Greenfield 1999). These materials have yielded satisfactory results, but with less ease of application and removal.

However, Xantopren® is relatively expensive material, is difficult to acquire, and requires a special application apparatus to use (Table C1). In addition, while Shipman (1981b:362) recommends Xantopren® as suitable for use with museum collections, Cook (1986:146) suggests that materials such as Xantopren® Blue can contain dyes that may stain specimens and should be avoided. In the current study, this characteristic was monitored in test subjects and was deemed negligible. As long as the fragility of specimens was kept in mind, the application of Xantopren® seemed to have no adverse effects to the EfPm-27 assemblage.

A test sample of the Xantopren® moulding material revealed it to be ideal for cut mark analysis. Figure C3 shows the lack of course grains in the Xantopren® material; imperfections and the rough appearance of the image are due to imperfections in the flat table surface that was moulded for the test. The Xantopren® moulding material proved to be far superior in ease and reliability of mould production, as well as in mould accuracy (Table C1). In addition, in contrast to the Jeltrate® moulds, Xantopren® moulds resisted warping and remained flexible over time rather than becoming rigid.

Figure C4 contrasts Jeltrate® and Xantopren® moulds of the same cut mark at the same location and magnification. The liquid, as opposed to powder, based material provided high definition in the moulds (Figure C4). This also allowed for high magnifications, compared to the necessarily low magnifications for Jeltrate® images. Low magnification images provide a wider field of view of the specimen but have the undesirable feature of lack of focus and fuzziness around the edges of the view.

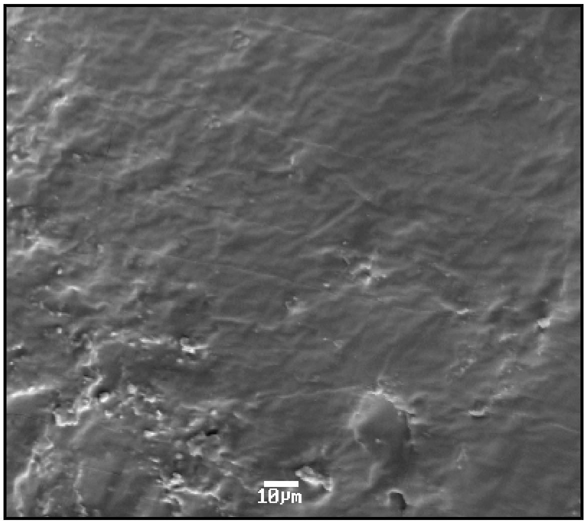

Figure C3. Detail of SEM image of test of Xantopren® moulding material (x300 magnification).

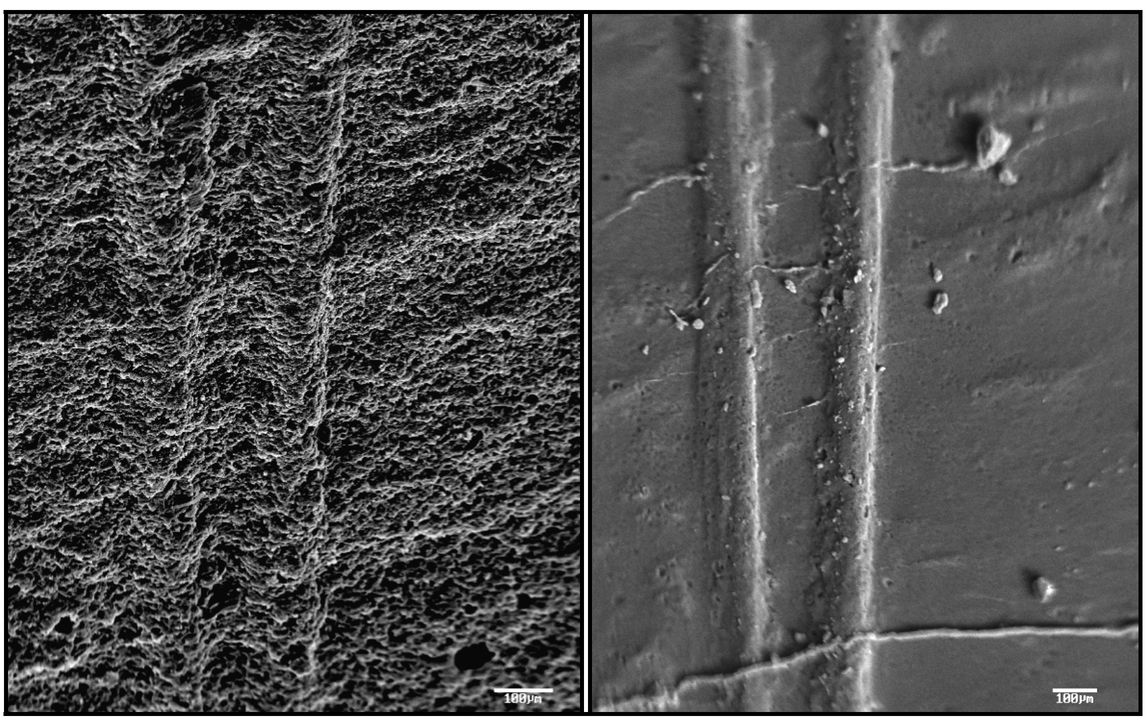

Figure C4. SEM images of Cat#231 at the same location (x60 magnification): (left) Jeltrate® mould; (right) Xantopren® mould.

The large grain size of the Jeltrate® moulds caused high magnification images to be confusing examinations of the mould material itself rather than features of the cut mark. For example, the cut mark crossing the bottom left corner of Cat#659 in Figure C5 is very difficult to perceive compared to the mould particles. However, the Jeltrate images did allow for an impression of the gross morphology of the cut marks (Figure C4).

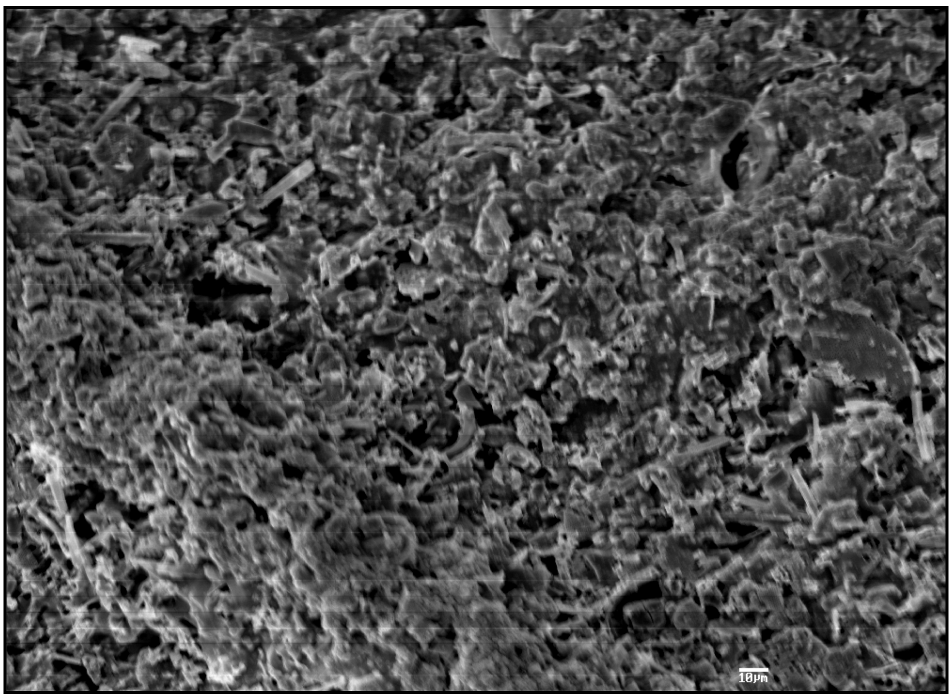

Figure C5. Detail SEM image of Jeltrate® mould of Cat#659 cut mark (x400 magnification); cut mark crosses bottom left corner.

A sample of Optosil® putty was also analyzed. This material proved to have a suitable lack of large grains but was excessively porous (Figures C6-C7). This may be a feature of the putty. It could also be a function of the method of Optosil® mould production, as the base putty must be mechanically mixed with the activator liquid by hand manipulation, potentially introducing fine air pockets.

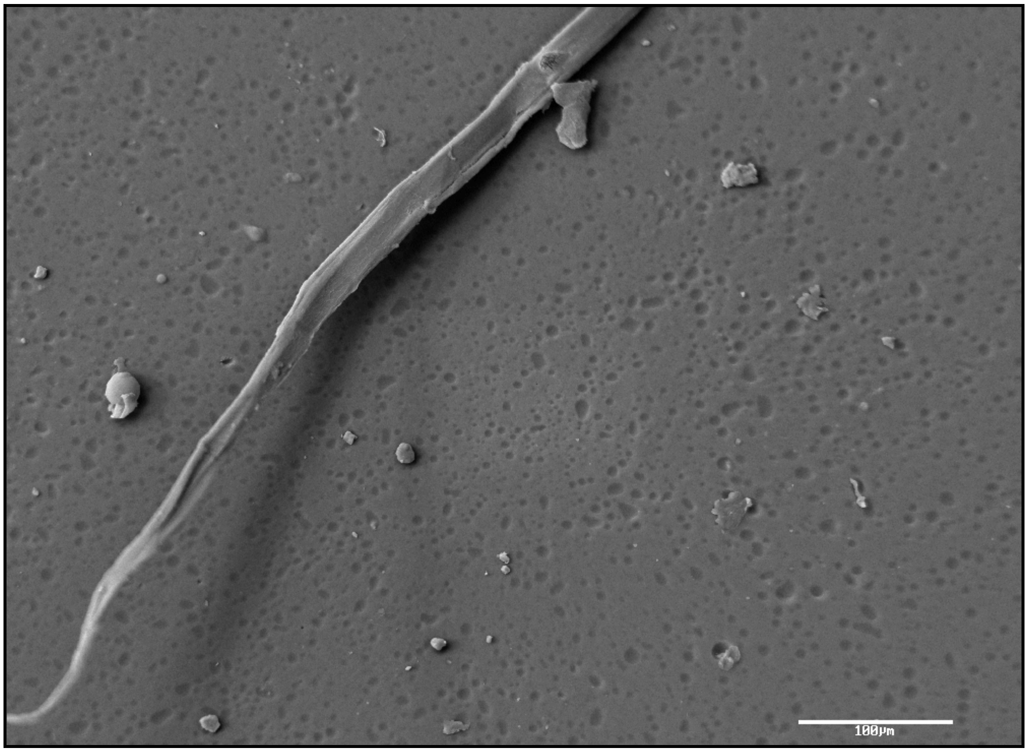

Figure C6. SEM image of Optosil® mould material (x200 magnification) showing vacuous form of mould and glue fragments.

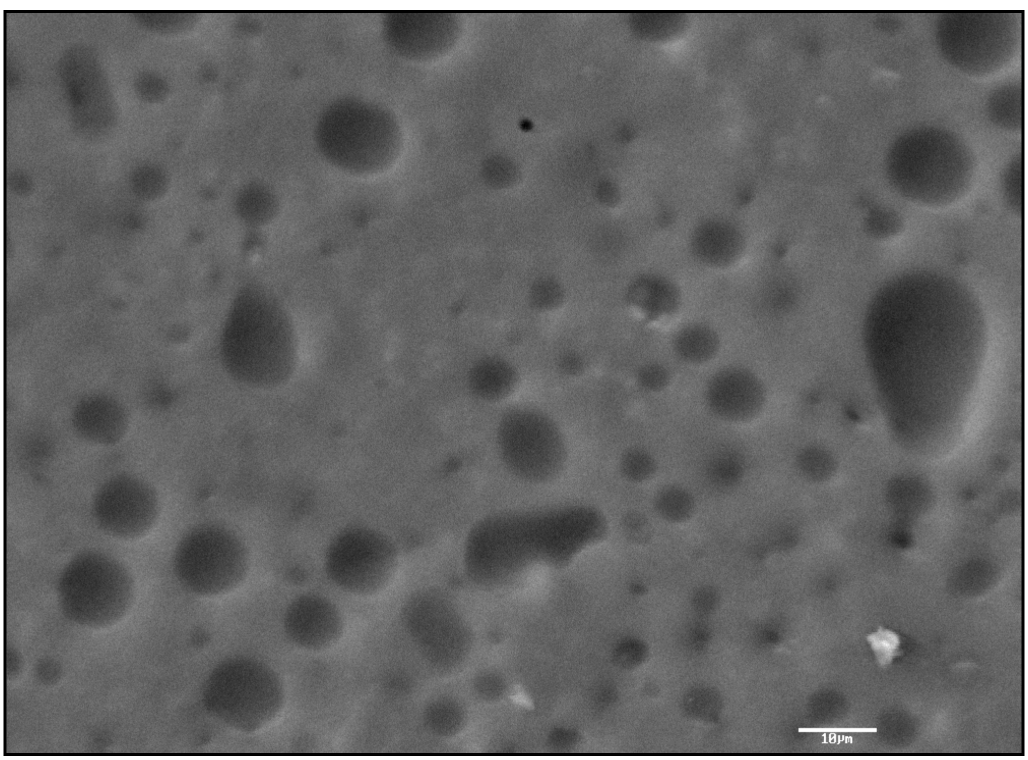

Figure C7. SEM image of Optosil® mould (x1000 magnification).

A combination of Xantopren® and Optosil® mould was also attempted using Xantopren® as the key moulding material next to the cut mark and Optosil® as a base. This would arguably have solved the difficulties with attachment of Xantopren® moulds to the SEM stands as the Optosil® was easily affixed to stands using common methods. Unfortunately, it appeared that the Optosil® tended to imprint its porosity onto the Xantopren® mould (Figure C8).

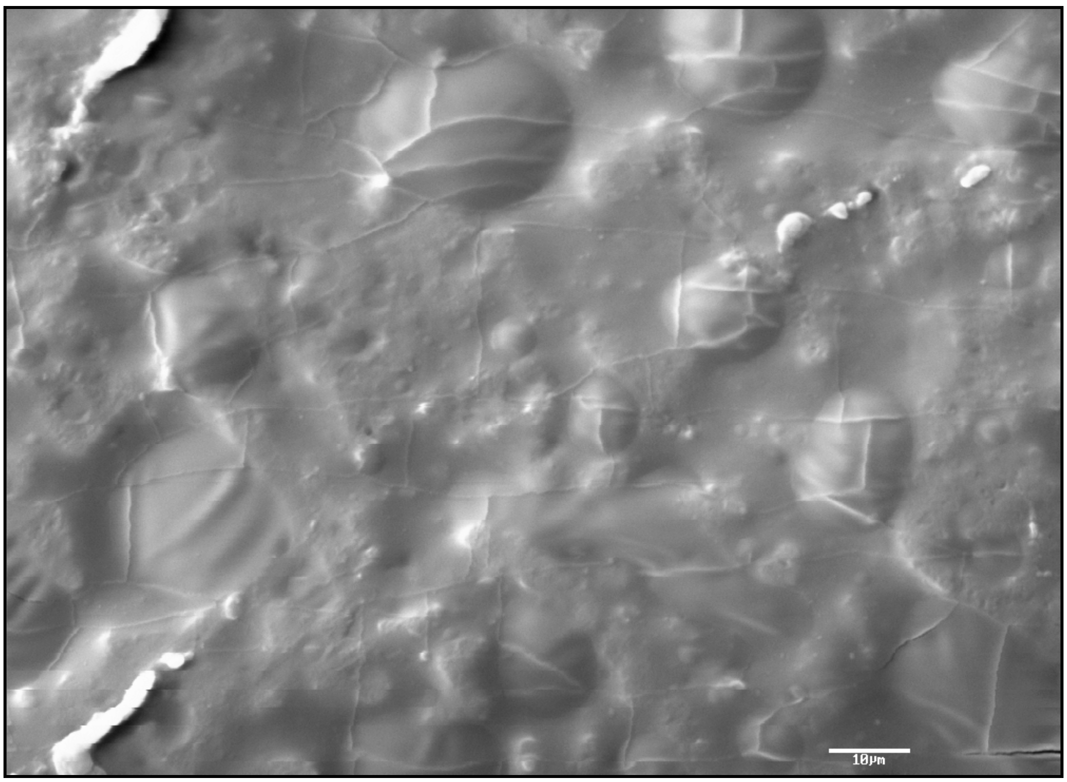

Figure C8. SEM image of Xantopren® and Optosil® combination mould (x1000 magnification).